Effects of Wind Turbines on Radar:

A Pilot Study of US Concerns

Trisha Auld, B.Bus.

Masters of Science in Renewable Energy Dissertation

Energy Studies, School of Engineering and Energy, Murdoch University

2011

Declaration

Except where I have indicated, the work in this dissertation is my own and has not been submitted for assessment in another unit, or at another educational institution.

Trisha Auld

Abstract

A substantial number of wind energy projects have recently been stalled or abandoned in the United States of America (US) due to concerns over the effects of wind turbines on radar and military sites. The US Department of Defence (DOD) has reported that utility class turbines can have a 'significant impact' on the operational capabilities of air defence radar, can interfere with military testing and training capabilities, and can obstruct Comprehensive Test Ban Treaty monitoring (DOD 2006). The American Wind Energy Association (AWEA) estimates 10,000 MW of wind generation capacity was held up or abandoned in 2009 due to such concerns (cited in Warwick 2010).

This dissertation is a pilot project that aims to look behind such public statements to:

1. Define the nature of US concerns pertaining to the effects of wind turbines on radar and military sites.
2. Determine the recent impact these concerns have had on wind energy projects in the US.
3. Identify and analyse proposed solutions to the problem.

Results of the literature review, case study analysis, and industry interviews conducted for this pilot study show:

1. Additional clutter, shadow, seismic noise and flight obstruction are the main concerns the DOD has with proposed wind projects.
2. DOD concerns have had an extensive impact on the rapid development of the US wind industry and could prevent the US from reaching its target of 20% of energy from wind energy by 2030.
3. Proposed solutions available to overcome DOD concerns are vast; however the range of solutions available, which are certified by the DOD, need to be expanded.

This pilot project is intended to provide a platform for further research into this issue.

Acknowledgement

I would like sincerely thank those who have contributed to following dissertation. Thank you to BP Wind Energy North America and Murdoch University for your generous financial contributions; to David Van Hoogstraten of BP for your encouragement and time, to Jonathan Whale and Trevor Pryor of Murdoch University for your sensible and calming academic guidance; to Erich Von Dietze of Murdoch University for your considered and helpful ethical steering; and finally to all the research participants who generously made the time to share their views.

Table of Contents

1. Introduction ... 1
   1.1. Research Scope and Objectives ... 2
   1.2. Research Methodology ... 2
2. Issue Context ... 4
   2.1. US Wind Industry ... 4
   2.2. US National Security ... 5
   2.3. Turbine Impact Assessment Process ... 5
   2.4. Fundamentals of Radar ... 6
3. Wind Turbines: US Causes for Concern ... 11
   3.1. Why Wind Turbines Affect Radar ... 11
   3.2. Effects of Wind Turbines on Radar ... 12
   3.3. Effects of Wind Turbines on Military Sites ... 16
4. Impact of Concerns on US Wind Development ... 19
   4.1. Scale of Impact Versus National Targets ... 19
   4.2. FAA Assessment – A Catalyst for Delay ... 21
5. Issue Mitigations ... 26
   5.1. DOD Approved Mitigations ... 26
   5.2. Proposed Technical Mitigations ... 29
   5.3. Evaluation of Proposed Solutions ... 38
6. Cooperation, Funding & Research ... 40
   6.1. Cooperation ... 40
   6.2. Research & Funding ... 42
   6.3. Issue Next Steps ... 43
7. Evaluation of Pilot Study Results ... 45
8. Conclusion and Recommendations ... 46
9. Glossary ... 47
10. References ... 50
11. Appendix 1: Addendum ... 504

1. Introduction

Wind energy is increasingly viewed as a viable option to expand renewable energy generation in the United States of America (US). US installed wind generation capacity accounts for 22% of the world's installed wind generation capacity (BP 2010), 2.3% of the US energy mix (AWEA cited in Science Daily 2011), and grew more than any other US energy source from 2008 to 2010 (BP 2010). The US Department of Energy (DOE) envisions that 20% of the country's electricity could come from wind energy by 2030 (DOE 2008). To support this vision, the current US Government aims to double US renewable energy generation by 2011 (Freshfields 2009) and supports wind energy development through tax incentives and government grants under the *American Recovery and Reinvestment Act* (ARRA) of 2009.

Despite strong growth in government support for the US wind industry, US wind energy projects are being stalled by concerns from government defence departments over the impact of wind turbines on radar and military sites. The US has a strong commitment to national security, with a defence budget of over $650 billion (DOD 2011). The country's policy on national security focuses on preventing acts of terrorism on American soil, and fighting war in Afghanistan to disrupt and dismantle al-Qa'ida (United States Government 2010). In serving this policy the US Department of Defence (DOD) has publicly advocated that utility class turbines can have a 'significant impact' on the operational capabilities of air defence radar, can interfere with military testing and training capabilities, and can obstruct Comprehensive Test Ban Treaty monitoring (DOD 2006).

The American Wind Energy Association (AWEA) estimated 10,000 megawatts (MW) of wind generation capacity was held up or abandoned in 2009 in the US due to radar and military site concerns (cited in Warwick 2010). Stu Webster (2010), speaking on behalf of AWEA members, testified to Congress in 2010 that the growth necessary to achieve 20% of US electricity from wind energy is unlikely to be achieved; without first resolving radar and airspace concerns.

1.1. Research Scope and Objectives

This dissertation is a pilot project that seeks to look behind such statements of concern to understand:

- What is the nature of concerns pertaining to the effects of wind turbines on radar and military sites in the U.S?
- How have radar concerns recently impacted wind energy developments in the U.S?
- What solutions have been proposed to resolve such concerns and how valid are they from a US wind development perspective?
- What type of support (e.g. governance and funding) is required to help implement viable solutions?

This pilot study is focused on solutions for the US. Examples of successful governance and mitigations from alternative countries will be analysed for their suitability to the US.

1.2. Research Methodology

This pilot project uses a synthesis of a literature analysis, case study analysis, and industry interviews. The literature survey and case study analysis cover public information from databases, news articles, wind/radar forums, and previous research. They aim to define radar and military site concerns raised around wind turbines, identify any impact that concerns have had on wind development in the US, and discover proposed solutions to such concerns from the US and the rest of the world (where applicable). The case study analysis aims to provide relevant examples from these areas.

The aim of the industry interviews is to enhance the findings of the literature survey by providing the insights from the wind development industry, impacted government agencies and radar experts. Representatives of these target groups will be asked open ended questions around the following areas:

- How viable are radar and military site concerns raised by the DOD?
- What impact have radar and military site concerns had on wind development projects in the US in the last 3 years (in MW delayed, rejected, abandoned)?
- How viable are the proposed solutions to these concerns?

- What is required (e.g. governance and resources) to implement the most viable solutions?

Note: Only non-classified information will be sought in these interviews

These questions may be tailored to include more detail questioning depending on the expertise of the participant.

Eight individuals were invited to be interviewed. Participants were interviewed in a semi structured manner over the phone, with a transcript of the interview being scribed throughout. Answers to both scripted questions and conversational leads were recorded. To ensure each interview was conducted in an ethical manner, guidance and ethical approval (number 2011/043) was obtained from the Murdoch University Human Research Ethics Committee for this research. Results of industry interviews will be presented under their relevant theme heading for the issue.

2. Issue Context

2.1. US Wind Industry

The US has over 35,000 MW of installed wind energy capacity, with the potential to power 9.7 million homes, and avoid 62 million tonnes of carbon dioxide emissions annually (AWEA 2009). This shows rapid expansion from its installed wind energy capacity of 2,500 MW ten years ago. Wind energy achieved an average growth of around 40% annually from 2004 to 2009 and at least 36 states now have utility class turbines installed (AWEA 2009), which are typically over 400feet (ft) (122m) tall and 300ft (92m) wide (Warwick 2010).

The US does not have binding federal renewable energy targets (AWEA 2009); however rapid wind energy development is strongly supported by the current government, which aims to double US renewable energy generation by 2011 (Freshfields 2009). The current government also supports the DOE's vision for 20% of US electricity supply to come from wind by 2030 (also known as '20/30') and intensive state wind energy targets reinforce this vision. In Massachusetts for example, the state government aims to have 2,000 MW of installed wind power by 2020; an aggressive target considering Massachusetts only had around 9 MW of installed wind energy capacity in 2009 (Butcher 2010).

Rapid industry growth has also been boosted by government incentives. Provisions in the *American Recovery and Reinvestment Act* (ARRA) allow production tax credits (traditional wind development incentives) to be converted into an investment tax during the economic downturn. Incentives for renewable energy research and manufacturing are also provided under *The Recovery Act*. These government incentives supported around 3,000 MW of new capacity in 2009 (AWEA 2009).

The DOE's 20/30 assessment estimates 16,000 MW of wind energy capacity will need to be installed each year by 2018 (DOE 2008) to achieve the 20% target. Representatives of the US wind industry are dubious this will be achieved without first resolving radar and airspace concerns pertaining to wind turbines (cited in Warwick 2010).

2.2. US National Security

The US Department of Defense (DOD) is America's largest and oldest government agency, with its headquarters at the Pentagon. The DOD manages a large inventory of installations in over 5,000 different locations and utilises over 30 million acres of land for its activities. The sites range from small half-acre single navigational aids to 3.6 million acre missile ranges (DOD 2010). The DOD website (2010) advocates:

"The national security depends on our defense installations and facilities being in the right place, at the right time, with the right qualities and capacities to protect our national resources. Those resources have never been more important as America fights terrorists who plan and carry out attacks on our facilities and our people."

For fiscal year 2012, a defence budget of $671 billion was been requested. This includes a $553 billion discretionary budget to fund base defence programs and $118 billion for overseas contingency operations focussed on Afghanistan and Iraq (DOD 2010).

2.3. Turbine Impact Assessment Process

The Federal Aviation Administration (FAA) in the US has the regulatory authority to review and evaluate the impact of new structures on civilian and military airspace use (DOE 2008). This impact assessment process is applicable to many new wind energy projects and is the mechanism through which many wind developments have been held up, delayed or abandoned. Wind projects are unable to start construction without FAA approval.

Wind farm developers are required to file a notice of proposed construction for each wind turbine within a wind project that may affect the navigable airspace. This is defined in the FAA Advisory Circular 70/7460 2K as:

- Objects greater that 200 ft (61m) in height above the ground level at its location.
- Objects within 20,000 ft (6098m) of a Public-Use or Military Airport or Seaplane Base where object would exceed a 100:1 horizontal slope from the nearest point on the runway.

- Objects within 10,000 ft (305m) of a Public-Use or Military Airport or Seaplane Base where the object would exceed a 50:1 horizontal slope from the nearest point on the runway.
- Objects within 5,000 ft (1524m) of a Heliport pad and the object would exceed 25:1 horizontal slope.

(FAA 2000)

Process guidelines also substantiate that developers are required to submit paperwork stating the exact locations of the wind turbines 30 days before ground breaking (Magnuson 2010).

To determine whether a proposed construction is a potential hazard to air safety or security, the FAA consults a number of relevant authorities, including the Department of Defence (DOD) and the Department of Homeland Security (DHS). A notice of ‘no hazard’ is issued by the FAA when there are no concerns about air safety caused by a proposed development. This enables a wind farm construction to commence from an air safety and security perspective. Alternatively, the FAA issue a notice of ‘presumed hazard’ when consulted authorities raise concerns over air safety or security. Notices of presumed hazard require wind developers to work in conjunction with the FAA and relevant authorities, in an effort to minimise potential hazards (DOE 2008). At this point in the process many wind development projects are delayed.

2.4. Fundamentals of Radar

2.4.1. Basic Radar Systems

‘Radio Detection and Ranging’, more commonly known as ‘radar’, is used in both civilian and military operations for air traffic control (ATC), air defence, and weather forecasting. A basic radar system consists of a transmitter, an antenna, a receiver, and a processor (DOD 2006). The transmitter emits pulses of electromagnetic energy, which bounce off objects, also known as ‘targets’, in a radar’s line of sight. The antenna and processor detect and analyse energy echoes reflected back to the radar (Auld 2006). The figure below illustrates the process of a basic radar system. The information contained in the reflected signal and the manner in which it is processed determines the basis of operation for a radar (DOD 2006).

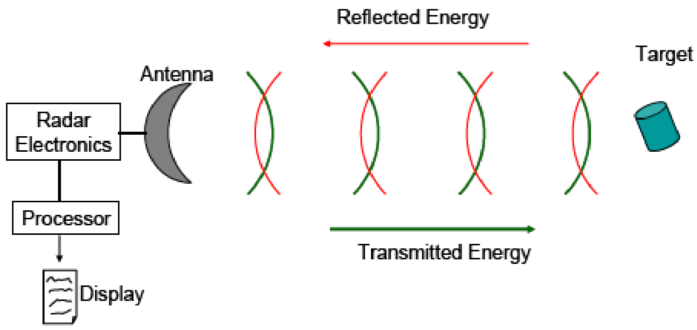


Figure 1- Basic radar system
Source: (DOD 2006, 11)

There are two main forms of radar surveillance systems, primary and secondary. Primary surveillance radar (PSR) uses the basic radar process above to provide a two or three dimensional representation of a target in a region (DOD 2006). A number of factors can affect a PSR's ability to process reflections off a target of interest, including; the power of the transmitter, the distance from the target, the size of the reflection [or radar cross section (RCS)] of a target, antenna geometry, obstructions, and reflections from other objects e.g. hills, buildings, wind turbines (DOD 2006).

In contrast to a PSR, secondary surveillance radar (SSR) uses coded signals to obtain information about a target. SSR systems are also called 'beacon' systems and help air defence staff distinguish between friendly and hostile aircraft. An SSR sends out a coded signal which is received by aircraft. The aircraft's transponder translates the signal and then transmits a coded signal back to the SSR (DOD 2006). This means SSR systems use much stronger direct signals from an aircraft's transponder, rather than weaker reflected signals used by a PSR. Consequently, SSR are typically unaffected by reflections from other objects (DOD 2006); an important point for understanding the impact of wind turbines on PSR and SSR.

2.4.2. Types of Radar Used in the US

The following section outlines radar types used by the DOD, FAA, and National Oceanic Atmospheric Administration (NOAA) in the US. Webster (2010) points out the US have a relatively aging radar fleet with around 80% of all US radars being implemented from the 1950s to 1980s.

Air Traffic Control Radar (ATC)

ATC radars consist of both primary and secondary radar systems and are used to monitor aircraft *in and around* air fields. Modern ATC radars typically have PSR coverage of up to 60 miles and SSR coverage of up to 120 miles (Raytheon 2011). There are 283 ATC radars of various models in the US. 110 are modern digital ASR-11 (deployed in the 1990s), 135 are ASR-10 (deployed in the 1980s) and 38 are analogue ASR-8 (deployed in the 1970s) (NWCC 2010). The figure above shows an example of an ATC radar with the PSR and SSR identified.

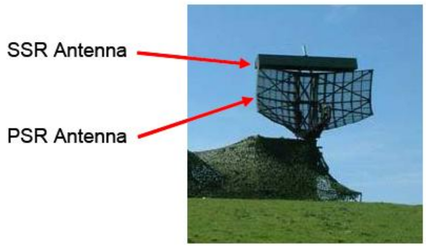


Figure 2 - UK Watchman ATC Radar

Source: DOD 2006, 19, Figure 11

Long Range Radar (LRR)

LRR (shown below) are described as the "back bone of primary surveillance in the US" (Blackman cited in NWCC 2010, 24). LRR track aircraft *in between* airports and Are used for air defence (Brenner *et al* 2008). Modern systems are digital, and provide coverage up to 250 nautical miles (nmi) (Aftergood 2000), while older systems are analogue (Seifert 2009). There are 128 long range radars of various model types in the US (NWCC 2010); these are predominantly located in perimeter states (Aftergood 2000). Two dimensional FPS-20, ARSR 1s and ARSR 2s are the most common type of LRR with 65 systems across the country. These systems were deployed in the 1950s and1960s and were upgraded in the 1980s. Modern three dimensional ARSR-4s, deployed in the 1990s, are the next most common with 43 systems in the US. There are also 13 ASRS-3s (deployed in the 1970s and upgraded in the 1980s) and 7 TARS systems (deployed in the 1980s) (NWCC 2010).

Figure 3 – ARSR-4 Radar
Source: Aftergood 2000

Weather Radar

There are 158 WSR-88D Next Generation Weather Radars (NEXRAD) in the US which are used to monitor weather conditions. The majority of these were deployed in the late 1980s (NWCC 2010). These radars create Doppler maps to illustrate rain, hail, and snowfall patterns (DOD 2006). The figure to the right shows US NEXRAD radar.

Figure 4 - US NEXRAD Weather Radar
Source: DOD 2006, 21, Figure 13

Missile Early Warning Radar (EWR)

EWR (shown below) are large, high powered phased array systems designed to detect and track objects with low radar reflectivity at long ranges with a high level of accuracy. These radars have a range in excess of 5,000 kilometres (km) and are required to discriminate between closely spaced objects; such as nuclear weapon re-entry vehicles and possible counter measures designed to confuse defensive systems. There are two EWR radars in the US, one on the east coast in Massachusetts and another on the west coast in California. (DOD 2006).

Figure 5 - US Beale Early Warning Radar
Source: DOD 2006, 20, Figure 12

2.4.3. Target Detection

Auld (2006) describes electromagnetic energy as ‘fairly indiscriminate in what it reflects off’ (5). Therefore ATC radar and LRR adopt particular processing techniques to distinguish between the electromagnetic echo of aircraft and the echoes of unwanted targets, referred to as ‘clutter’. Examples of clutter include objects such as buildings and towers (Kelly 2011). The parameters radar use to identify aircraft from clutter are described by Kelly (2011) below:

1. Aircraft have a high level of reflectivity, known as a radar cross section (RCS). Radars can use threshold filters to avoid detection of objects with a low RCS.

2. Aircraft occupy predictable elevations. Radar antennae can be oriented to focus on echoes from a particular elevation.
3. Aircraft are in motion at the moment they reflect electromagnetic energy causing an apparent change in frequency of the return, also known as a ‘Doppler’ effect (Wolff 2011). Radars can use moving target indication (MTI) and moving target detection (MTD) to differentiate and focus on echoes from moving targets, cancelling out stationary objects.
4. Aircraft do not hover or remain still for extended periods of time. Constant false alarm rate (CFAR) processing can be used to determine the average background echo per cell of radar coverage. Amplitude thresholds can then be used to only pick up objects with echoes above that of the background average.

RCS thresholds, antennae orientation, MTI/MTD processing, and CFAR processing are all minimum standard for most modern radar (Kelly 2011). Weather radar uses similar parameters to distinguish between actual and unwanted weather echoes (EURMETNET 2005).

3. Wind Turbines: US Causes for Concern

3.1. Why Wind Turbines Affect Radar

Wind turbines affect radar as their echo characteristics often match those of an actual aircraft or storm pattern, which radar seeks to track. For example:

- Wind turbines have incredibly high reflectivity. Studies conducted by the DOD (2006) showed that the RCS for a turbine could be greater than that of a long haul, wide bodied aircraft such as a 747. Therefore RCS filters have difficulty in differentiating wind turbines from aircraft. The following figure illustrates the RCS of a 1.5MW wind turbine against other objects that may be detected or rejected by radar.

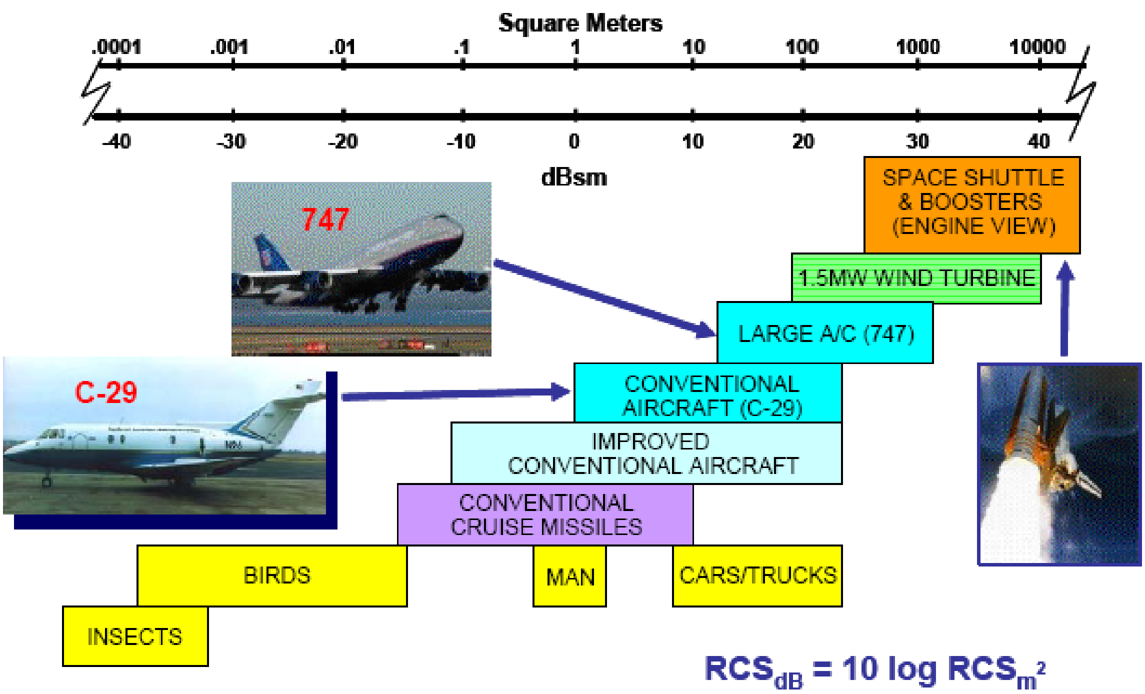


Figure 6 - Comparison of RCS for different objects
Source: DOD 2006, p15

- Utility scale wind turbines can occupy similar elevations to aircraft, especially when located on hill tops. Radar requirements to monitor low flying aircraft means wind turbine and aircraft can share the same elevation (Kelly 2011). Therefore typical antennae orientation can have difficultly filtering out wind turbines.

- Wind turbine blades are moving at the time of reflection, meaning that typical MTI/MTD algorithms are unable to detect the difference between a turbine and an aircraft (Kelly 2011).
- Wind turbine echoes can vary over time depending on wind direction and blade orientation. This causes problems for CFAR processing as wind turbines can cause consistently high background echoes which can raise the CFAR threshold. This means smaller aircraft, with a lower RCS than a turbine, may not be detected. Additionally, radar may treat inconsistent large returns from turbines as actual aircraft targets (Kelly, 2011).

Based on the information above, typical processing methods used by radar to focus on valid targets can be ineffective at filtering out the unwanted echoes or 'clutter' caused by wind turbines.

3.2. Effects of Wind Turbines on Radar

Wind turbines cause two main types of interference with radar, direct interference and Doppler interference. Direct interference is caused by the high reflectivity of the turbine components: towers, nacelles, and blades. This can reduce the sensitivity of the radar via increased background noise, create false readings, and shadow areas of radar coverage. Alternatively, Doppler interference is caused by the moving blades of a turbine which can cause false targets, false MTI/MTDs, and impacts both airborne and fixed radar (Seifert 2009). The following section explains each of these impacts in more detail. A variety of research has been conducted which verifies the following impacts of turbines on ATC, LRR, EWR and weather radar. A selection of this research is summarised below.

Organisation	Research Summary
Network of European Metrological Services	French research into a wind farm's capacity to block beams, cause clutter, and cause Doppler interference on weather radar. Results show wind farms up to 30km from the radar have a high potential to degrade meteorological data and impact weather "nowcasting and forecasting" (EUMETNET 2005, 2).
US Department of Commerce – National Telecommunications and Information Administration	US study into the effects caused by wind turbines, greater than 250 feet (76m), on ATC and FAA radar. Results show there are numerous documented "cases of deleterious effects" (Lemmon *et al* 2008, 1).
UK Royal Air Force	UK tests to determine the effects of wind farms on ATC primary surveillance radar. Results confirmed shadowing and clutter effects which can be "highly detrimental to the safe provision of Air Traffic Services" due to a decrease in 'probability of detection' and the inability to differentiate between turbine-induced clutter and actual aircraft (UK Royal Air Force 2005, 1).
Keele University Applied and Environmental Geophysics Group (UK)	UK tests to determine seismic and infrasound noise generated by wind farms in the vicinity of Eskdalemuir seismic monitoring site in Scotland. Results indicated impacts of seismic noise could be controlled through the allocation of a 'noise budget'; within which detection capabilities are not compromised (Styles *et al* 2005).

Table 1 - Research Confirming Wind Turbine Interference

To better understand the nature of US DOD concerns, the DOD's 2006 report *'Effects of Wind Farms on Military Readiness'* which also confirms turbine interference effects will be referenced extensively in the following sections.

3.2.1. Shadowing & Clutter

Shadowing

The DOD (2006) describe the shadowing effect wind turbines have on radar in the following way:

> "Objects in the path of an electromagnetic wave affect its propagation characteristics. This includes the actual blockage of wave propagation by large individual objects or interference in wave continuity due to diffraction of the beam by individual or multiple objects" (DOD 2006, 13-14)"

The following figures illustrate complete and partial blocking of electromagnetic waves and diffraction of electromagnetic waves. Clusters of wind turbines typically cause diffraction of a radar's electromagnetic energy and therefore create shadow zones or blind spots where monitoring is less efficient. The amount of shadow incurred will be dependent on the size of the wind farm and the topographical features which surround it.

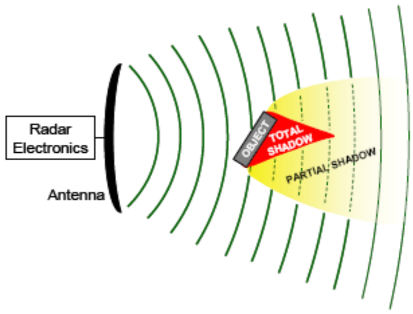


Figure 7 – Shadowing
Source: DOD 2006, 14

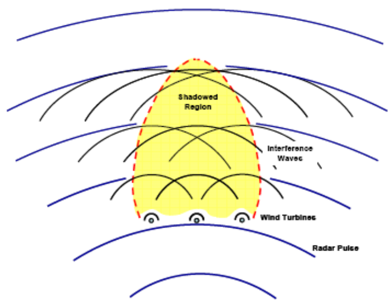


Figure 8 - Diffraction
Source: DOD 2006, 14

Clutter

Clutter is another key effect that wind turbines can have on radar. DOD (2006) defines 'clutter' as 'any unwanted reflected signal that enters the radar receiver and can interfere with the determination of the desired attributes of the target of interest' (11). Ian Chatting, Head of Research in Britain for Vestas – the world's largest wind energy company, explains wind farms cause a cloud of reflected signals known as 'clutter'. As an aircraft flies into this cloud it is difficult to determine whether it is the same or an alternative aircraft that has come out (cited in Reuters 2010).

DOD (2006) advocate that ‘clutter’ could occur if any portion of the turbine appeared in the radar’s line of sight and exceeds accepted RCS noise thresholds. Studies conducted by the DOD (2006) showed the RCS for a turbine could be greater than that of a long haul aircraft. As wind turbines are stationary and near the surface of the earth, this appears as ‘clutter’ on air defence radar. The amount of clutter is in direct proportion to the number of turbines within the line of sight of the radar. The DOD (2006) study concluded that a single turbine located at a distance from the radar will have minimal impact; however a large number of turbines over a wide sector of the radar’s coverage will significantly impact its performance. This is supported by Ministry of Defence research trials in the United Kingdom.

Impacts of Shadow and Clutter

When asked about efforts to improve the range of technical mitigations available to overcome wind/radar issues, the Wind and Radar Expert interviewed by the author explained, “There is military concern around the use of wind farms (clutter and shadow zones) by unfriendly aircraft to transition below the radar level of detection.” Thereby allowing unfriendly aircraft to conduct missions undetected. The Wind and Radar Expert extended his answer to say that drug trafficking was an area of military concern for such a manoeuvre. Magnuson (2010) suggests this DOD concern also pertains to pilots who have hijacked a plane. Schleck Associates (2010) suggest clutter and shadow zones could make it hard to maintain security for potential terrorist targets. The DOD (2006) highlight that shadow and clutter areas may minimise the tie that security forces have to react to potential threats.

An interview with a Military Pilot with US experience conducted by the author confirmed that it is possible for drug traffickers to have the appropriate flight equipment to fly below the radar (e.g. helicopters or jets). When asked about the feasibility or terrorists or drug trafficker having access to such assets the Military Pilot said, “It’s absolutely plausible. Drug traffickers looking to move product across US borders have been known to use submarines. Having access to a jet is definitely not out of the question.” In considering this option the Military Pilot added “An important consideration is the distance between the take off point, the wind farm, and potential targets” pointing out that different aircraft types would have different refuelling requirements and therefore different capacities to complete such a mission.

Theoretically, the inability of a radar operator to track an aircraft for a short period over and near wind farm is therefore a valid concern. Presumably proposed wind energy sites near potential terrorist targets or near potential trafficking entry routes would therefore have lower acceptance for loss of coverage. The DOE (2008) website however points out, “Wind developers have successfully installed over 21,000 megawatts of wind power capacity across the US and 93,000 megawatts across the world in the past 20 years without one documented case of enabling an attack on any nation.” This leaves the question open as to how significant this theoretical threat is.

Shadowing and clutter also affect weather radar. The Forth Worth Star (2010) reported that clusters of turbines near Albany in the US produce radar shadows to the north and west of Dyess. These shadows are of concern as they could potentially hide the appearance of severe weather approaching a base. Butcher (2010) describes how a wind turbine at the Jimney Peak ski resort in Hancock produces a signature resembling a thunderstorm, which cannot be distinguished from heavy rainfall. Kalinowski (2010, cited on www.faa.gov) explains how the false appearance of storm activity on Next Generation Weather Radar (NEXRAD), caused by wind farms, makes it hard to provide accurate weather information to pilots; therefore decreasing the accuracy and safety of weather forecasts.

While the pilot study results indicate shadow and clutter have adverse affects on radar, is there an acceptable level of interference for radar? From an interview conducted by the author with a Wind and Radar Expert it was found that “Just because a radar can see a turbine, that doesn’t mean the radar cannot do its job. The aviation industry is of the view that a little bit of sparkle is manageable, while the military are concerned with any loss of coverage…The metrics you use to determine what is allowable are very specific to the site.” the Wind and Radar Expert said when asked about promising wind/radar mitigation technologies.

3.3. Effects of Wind Turbines on Military Sites

Beyond radar interference, Dougherty (2008) identifies obstruction and safety as additional concerns the DOD have related to wind turbines. Dense development of wind turbines near airspace, test ranges, and training ranges used by the US military can occupy the same altitude as aircraft. Wind turbines can be over 400ft tall (122m) (Warwick 2010) and military flight training missions can be as low at 10ft (3m) (obtained from author's interview with a Military Pilot); meaning wind turbines can physically obstruct low flying missions or aircraft during take off and landing. A representative of Dyess Air Force Base in Abilene, where more than 2,000 turbines have been built within a 100 mile radius, advocated that wind turbines could pose hazards for B-1 bombers and C-130 transports used in the area. Base officials also found wind farms in West Texas interfered with low attitude training missions that can extend up to 120 miles from the base (Fort Worth Star 2010). The DOD (2006) highlights that a single turbine poses the same aviation obstruction as radio antennas and cell phone towers, and as such could be mitigated through the same process; however the number and proximity of turbines being installed makes them harder to mitigate with traditional measures.

Overhead transmission lines associated with wind farms also provide a flying hazard for aircraft, which poses a safety risk to flight and weapons training operations (DOD 2006). From the interview conducted by the author with a Military Pilot with US experience, it was confirmed that: "Both the poles and the lines provide obstacles to aircraft. The lines are particularly hard to see while using night vision equipment". The Military Pilot added when asked about the validity of such concerns, "There have been many aircraft accidents due to wire strike. They're definitely a concern for pilots on low flying missions". Flight training and testing concerns however, are likely to be restricted to only particular areas of the US. Tom Vinson, a spokesperson for AWEA who was interviewed by the author, said "There's a limited number of training areas in the US for such DOD activities. Issues around training areas primarily come from Nevada, California, and Texas." Vinson said when questioned around the split between objections due to military sites versus radar.

3.3.1. Seismic and Infrasound Noise

Seismic and infrasound noise is the final publicly stated area of concern for military operations. Wind turbines produce seismic and infrasound noise that could "contaminate monitoring stations providing data to support the Comprehensive Test Ban Treaty (CTBT) and US nuclear explosion monitoring effort" (DOD 2006 Appendix 2, 61). There are 4 primary and 10 auxiliary International Monitoring Systems (IMS) and several Atomic Energy

Detection Systems located in the US. These systems use a seismometer array to monitor nuclear explosions in line with the CTBT (DOD 2006). Studies by Styles *et al* (2005) confirm that sophisticated equipment such as seismic arrays can detect seismic noise caused by wind turbines.

Interference with military design and development sites was also confirmed as a viable concern. A Wind and Radar Expert interviewed by the author said, “A wind turbine changes the environment meaning there isn’t the same baseline for testing from one day to the next.” The Expert said when commenting on efforts to increase the range of viable technology solutions. These results are confirmed by seismic noise tests conducted in the UK at the Eskdalemuir; however these tests also pointed out that only the most sophisticated monitoring equipment would be affected (Styles *et al* 2005).

4. Impact of Concerns on US Wind Development

4.1. Scale of Impact Versus National Targets

In 2009 10,000 MW of proposed wind energy generation capacity was delayed in the US (AWEA, cited in Warwick 2010). From interviews conducted by the author with Tom Vinson from AWEA, it was revealed the approximately another 10,000 MW was delayed in 2010 and that no data had been collated for 2011. The following impact map presented by Seifert (2009) shows existing wind projects (in blue) and proposed wind projects affected by radar interference issues (in purple) against radars used by the DOD (in red). This map demonstrates that numerous projects, many of substantial MW size, are affected by this issue.

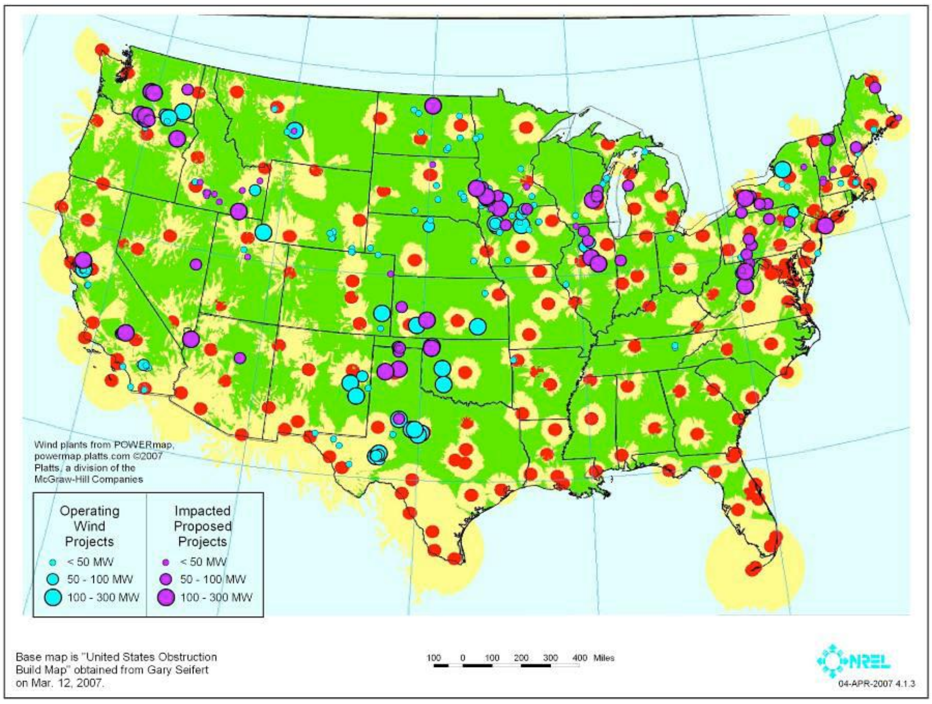


Figure 9 - Impact Map 2009
Source: Seifert 2009

The overall impact for the US wind industry is outlined in the following figure, which shows delayed wind capacity and implemented wind capacity against the growth forecast required to achieve 20% of US energy from wind by 2030.

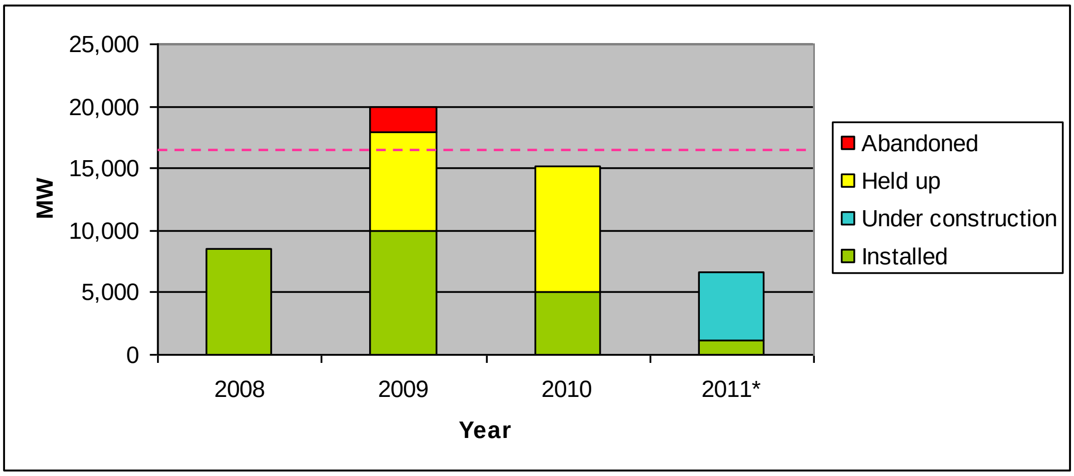


Figure 10 - Issue Impact: MW Installed v.s. DOE 20% 2018 Target

*Source: (Graph data sourced from AWEA (2011, 2010, 2009, 2008), interview with Tom Vinson (2011), AWEA (cited in Warwick 2010), and Blackman (2009)). Notes: Dashed red line represent '20/30' target installation, * 2011 first quarter data only, 'Held Up' and 'Abandoned' information available for 2009-2010 only.*

The above figure indicates a significant amount of wind development has been held up in the US in recent years. Recent wind energy implementation falls well below the '20/30' target capacity required to be obtained by 2018 (shown by the dashed line). Based on this comparison, it appears this impact could prevent the US wind industry from meeting the '20/30' target without a rapid increase in wind energy implementation. This is reinforced by the following figures which show '20/30' target wind energy installation and wind energy implementation to date.

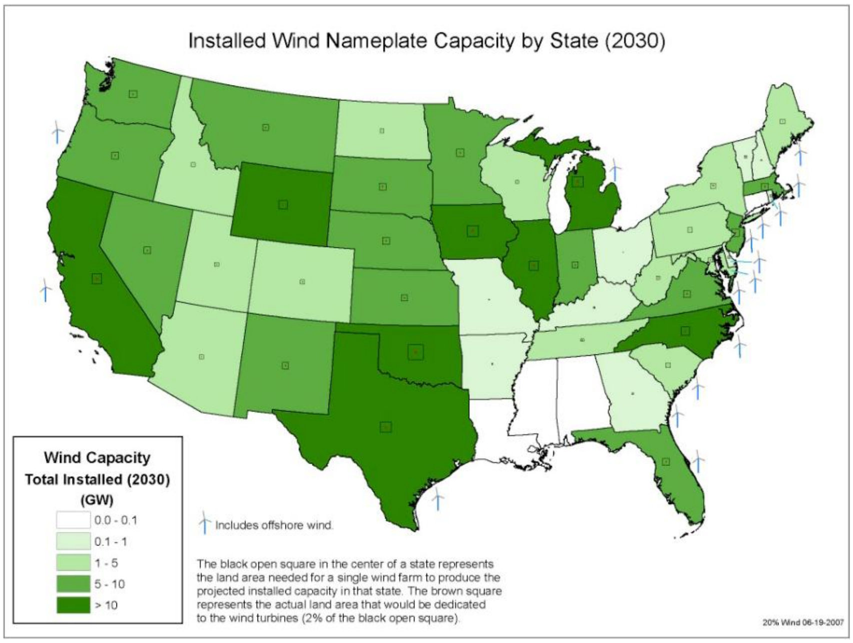


Figure 11 - 2030 vision for wind energy development
Source: Seifert 2009

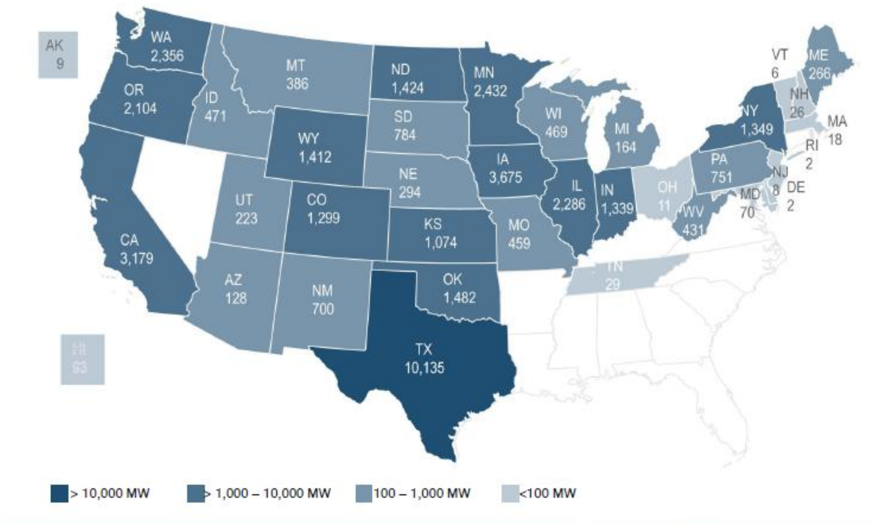


Figure 12 - US Wind Power Capacity Installations by State (2011)
Source: AWEA 2011,6

4.2. FAA Assessment – A Catalyst for Delay

A review of the literature indicated the existing FAA process for the notification and review of proposed wind farm constructions appears to suffer inefficiencies related to timing and cooperation. In 2010 the Deputy Undersecretary of Defence for Installation and Environment, Dorothy Robyn, voiced concern that wind developers were notifying the FAA late in the wind project approval process; often after selecting sites and engaging investors.

Ms Robyn identified that late notification limits the scope for collaborative efforts to identify potential issues and mitigation options (cited in Magnuson 2010). Alternatively, Levitan (2010) shows how input from government agencies has been uncoordinated and also last minute. This is demonstrated in Caithness Energy Shepherd's Flat wind development project, summarised in the case study below.

Case Study – Shepherd's Flat Wind Energy Project.

Shepherd's Flat is a 909 MW wind farm, proposed by Caithness Energy to be built in northeast Oregon (Levitan 2010).The project is set to be the largest wind farm in the world (Eilperin 2010). It involves a 1.4 billion US dollar turbine deal with General Electric (Learn 2010), is expected to avoid over 1.2 million tonnes of greenhouse gas emissions per year, and will create over 400 construction and 35 permanent jobs (Coal Geology 2010) in an economically depressed community (Eilperin 2010). By 2010 the project had been in development for almost nine years (Eilperin 2010). Caithness had been through more than four years of permit approval with county, state and federal governments, and had worked out concerns with the US Navy. Despite being notified of the project 3 years earlier (Air Force Times 2010), the US Air Force raised concerns 'at the 25th hour' about the turbines' potential to create further clutter and aircraft tracking interference issues for the long range Fossil radar at Ore, over 70 miles away. This denied the project its final FAA permit required for construction (Eilperin 2010). If construction was not completed by 2012 Caithness would lose its stimulus funding under the *American Recovery and Reinvestment Act.* Construction delays therefore could potentially damage the project's viability (Levitan 2010).

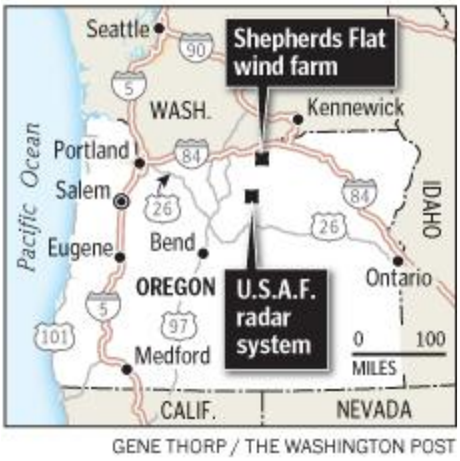


Figure 13 – Shepherd's Flat Project
Source: Washington Post (2010)

Eilperin (2010) reports the Air Force's action 'sparked an intense lobbying battle and White House-led negotiations' by senior Obama officials trying to avoid a decision which could cost America 16,000 jobs. Oregon senators, Wyden and Merkley, alongside Caithness and

General Electric officials also lobbied the White House; with Wyden using his nomination for future DOD staff as a bargaining tool to help ensure the issue was resolved. Merkley's Press Office (2010) reported that after 'a months long stand off' the Pentagon announced it would no longer block the project and would instead upgrade the nearby radar system, improving its ability to cope with clutter. A move that would 'eliminate the threat to other planned wind farms in the area'.

The lack of coordinated consultation for affected agencies was further highlighted by Tom Vinson, a representative of AWEA, who advocated (in an interview with the author) that vigilant wind developers attempt to engage relevant military input as soon as possible. Vison said when commenting on the 'next steps' required to progress the issue. Vinson also commented that military departments are not always responsive and collaborative efforts to identify and resolve hazards can be inconsistent (cited in Magnuson 2010). The lengths to which wind developers can be prepared to go to in order to avoid such issues is reinforced by claims from Kalinowski (2010) that primary FAA radar leaseholders have been offered financial incentives from wind developers not to renew their FAA contract and to lease to wind developers instead (cited on FAA website 2010).

4.2.1. Inhibiting Concerns – Science or Politics?

The congressional battle required to progress the Shepherd's Flat wind project, opens questions about the extent to which radar and military site concerns are genuinely scientific and to what extent they are political. Iberdrola Renewables, another company with wind developments in the Shepherd's Flat area, revealed that when radar issues have been raised in the past developers have been helped by Congress members, who are keen to bring employment to the area (cited in Levitan 2010). This political intervention would appear to override the scientific intention of the FAA impact assessment. This overriding can be interpreted in various ways:

1. Genuine DOD concerns may be being superseded by political agendas for economic development. The extent of political intervention required in the Shepherd's Flat case study could be testament to this interpretation.

2. DOD concerns may be less scientific and more political than publicly advocated. Recent military base closures may be a potential motive for preserving current base environments. Watson (2010) reports that 20 major military installations will be shut down by 2011 under the DOD Base Closure Alignment Commission. Watson (2010) recognises that base closure can have a negative economic impact in rural communities reliant on military business and employment. Based on this information it could be possible that wind turbines, which have the potential to degrade radar coverage and military sites, could be objected to in order to preserve the quality of base facilities and therefore help prevent a base from being selected for closure.

In evaluating the contrasting agendas of rapid wind development and national security, Seifert (2006) argues the issue matters when wind farms pose an unreasonable risk to national security and the benefits offered by the wind farm do not outweigh their interference impact. Providing an objective assessment of this balance, which is supported by Congress, remains a current challenge for the FAA impact assessment process.

4.2.2. DOD Energy Siting Clearing House

Tom Vinson, an AWEA spokesperson interviewed by the author, said the DOD has taken measures to improve the FAA impact assessment process (when asked about inefficiencies in the FAA assessment process). Vinson stated that the DOD have reorganised how they engage with wind developers, “Under Section 358, fiscal year 2011, of the *National Defence Authorisation Act*, they have developed a one-stop-shop for developer engagement called the Department of Defence Energy Siting Clearing House… The Clearing House has been methodically going through the backlog of development applications and sorting them out” Vinson said. The new process has been thought to be a positive move according to the author’s interview with Vinson. Key engagement changes, cited from the author’s interview with Tom Vinson, include:

- The proposed construction notice period for wind developments has been increased from 30 to 45 days.
- The Clearing House provides one access point to all relevant authorities at the Pentagon and is the only place for an official DOD response to a proposal.
- Only four people within the DOD now have the authority to say ‘no’ to a proposal.

Tom Vinson also pointed out, when interviewed by the author, “There are still some issues with individual services not being as collaborative as the Clearing House, however overall we’ve received positive feedback... People feel like they have access and their concerns are being heard”. While these changes appear to improve some of the issues related with the FAA process, whether the Clearing House is able to provide an objective justification for concerns that lead to a balanced assessment of the impact against the benefits of wind energy proposals is an important question. A spokesperson from the Clearing House was invited to be interviewed by the author to discuss this topic, however the spokesperson was unable to participate due to a busy schedule.

5. Issue Mitigations

Wind industry participants acknowledge there is no single solution to radar and military site concerns due to variables such as: location, radar type, mission type, and terrain type in each proposal (Magnuson 2010). The following section outlines DOD approved and proposed mitigating solutions to the issue.

5.1. DOD Approved Mitigations

The DOD in *'Effect of Windmills on Military Readiness'* (2006) concluded non- technical solutions to be the only proven mitigation to avoid the degradation of radar capability and interference with military training due to wind turbines. Non- technical solutions involve avoiding placing wind turbines in a radar's line of sight via zoning, terrain masking or terrain relief.

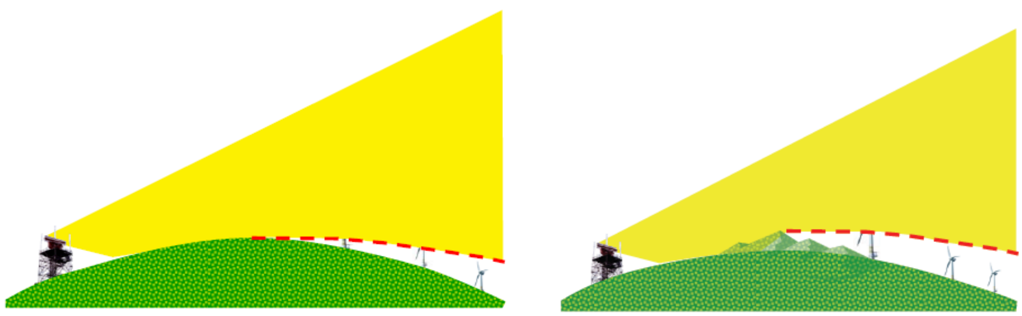
5.1.1. Zoning

Zoning refers to placing turbines a predetermined distance from a radar to avoid interference. The aforementioned DOD report (2006) recommends a distance of 30 nautical miles (nmi) would be required for turbines with blade tips that protrude over 300 ft (91m) above the local terrain. Zoning is a mitigation supported by policies pertaining to wind turbine siting in many European countries. In Austria, wind farms greater than 10km from an air defence radar will receive no objections. In The Netherlands, only wind farms within 15 nmi (approx 24 km) from a military radar require review. In Germany, policy enforces a protection zone of 10km around all ATC radars, with an area of interest up to 18km from ATC radars. These policies address military and civilian concerns over radar shadowing (for Germany and the Netherlands), electromagnetic interference and obstacles to low flying routes (in Austria) (DOD 2006). Zoning is a mitigation also used in United Kingdom Civil Aviation Authority policy as a means to manage shadowing and false plots on secondary surveillance radar (SSR). Turbines over 24km from an SSR are not thought to impose a problem (Kelly 2011). For primary radar in the UK all proposed wind turbines in the line of sight of the radar must undergo consultation with the UK Ministry of Defence, regardless of distance (DOD 2006).

Zoning is also a technique that has been used to overcome seismic noise interference for nuclear explosion monitoring in the UK. Studies in Eskdalemuir in the UK, site of the longest operating seismometer array and very good wind development areas, found that turbines within 10km of nuclear monitoring sites should be prohibited (Styles *et al* 2005). From 10km to 50km, the study concluded that wind turbines should not exceed a predetermined ‘noise budget’, and turbines over 50km from the radar should have no restrictions applied pertaining to this monitoring type (Styles *et al* 2005). The method used to determine these protocols has been accepted as sound by the DOD (2006) at which time recommendations were made for similar testing in the US, on a site to site basis to allow for differing background seismic noise.

5.1.2. Terrain Masking and Relief

Under UK, US and European policies mentioned in the previous section, turbines may be placed closer to the radar after further analysis determines there are no effects or the effects can be suitably mitigated. Non-technical solutions to facilitate this include ensuring there is elevated terrain between the radar and the turbine (terrain masking) or ensuring the elevation of the radar is above that of the turbine (terrain relief) (DOD 2006). The following figure illustrates how terrain masking helps remove turbine interference on a radar system. Kelly (2011) also identifies terrain masking as the “simplest method of mitigation” (17).



No terrain masking – majority of turbines in radar line of sight

Some terrain masking – less turbines in radar line of sight

Figure 14 – Illustration of Terrain Masking
Source: DOD (2006) Figure 30 and 32, 42-43

Analysis using wind farm models and terrain databases is required to determine whether this mitigation is suitable for a particular wind farm. The DOD (2006) advocate that while the analysis is not complicated it can be time-consuming.

5.1.3. Viability of DOD Approved Solutions

The practicality of using zoning alone can be limited due to the vast distribution of US radar. Seifert (2009) highlights this through the following figure which displays recommended turbine siting areas (in green) based on radar location (red zones indicating a 20nmi buffer zone).

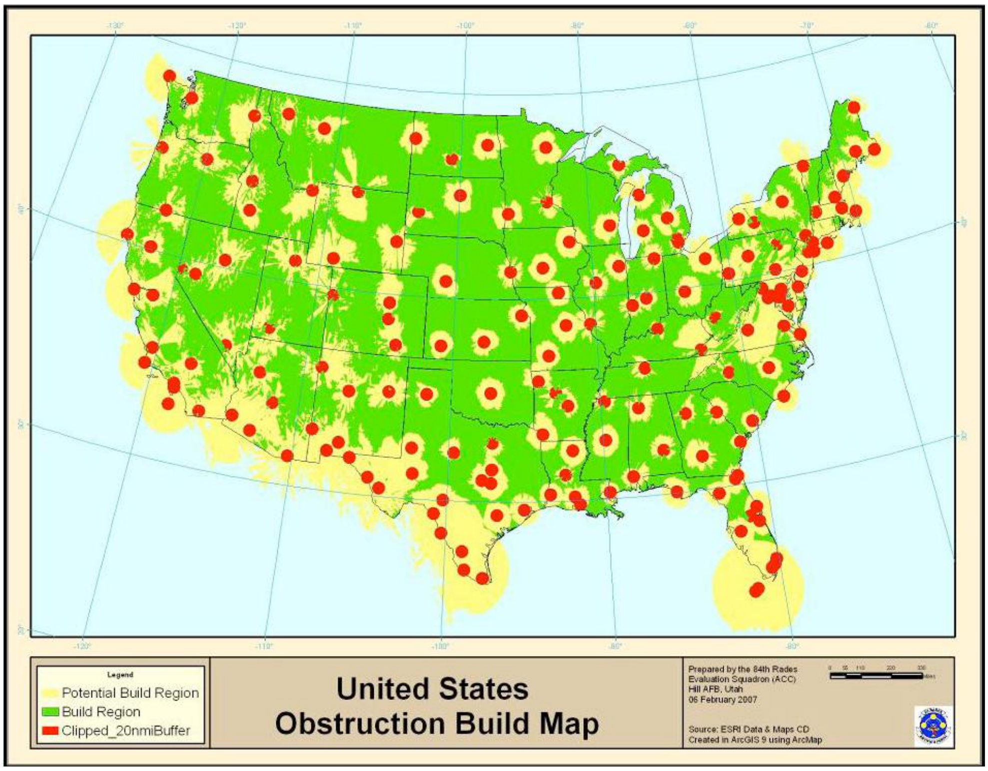


Figure 15 – Recommended Turbine Siting Areas
Source: Seifert 2009

While this map implies substantial unaffected areas for wind development, Bill Troia, International Business Developer for Long Range Radars at Lockheed Martin, identified a key reason for competing land use between wind farm and radar and military training sites; noting that flat, open areas with good visibility to the horizon are desired for both uses (cited in Magnuson, 2010). In addition, Ed Ciardi from the National Oceanic Atmospheric Administration (NOAA) acknowledged that altering the position or orientation of turbines could represent a loss in energy productivity or efficiency for wind developers (cited in

NWCC 2010); representing an opportunity cost that could be considerable. Alternatively, Kalinowski (cited on www.faa.gov 2010) suggests moving the radars to facilitate zoning is an impractical option. Additional radars may be added, but existing coverage cannot be lost. The FAA does not have a stock of spare radars and new radars would require a change in national airspace systems e.g. reporting points and airspace fixes.

Brenner *et al* (2008) argues non-technical solutions alone are narrow-sighted, stating the 2006 DOD report favoured to "block the installation of offending turbines, rather than to attempt to find technical means of ameliorating the turbine impact" (4). The following section explores a range of technical solutions that have been proposed to help solve the issue.

5.2. Proposed Technical Mitigations

Kelly (2011) suggests, where non-technical mitigations such as terrain shielding are not possible, there are three theoretical ways to limit the impacts of wind turbines on radar:

- Improving radar design to enable radars to distinguish between wind turbines and actual targets e.g. radar upgrades, gap fill radar.
- Reduce the reflectivity of the turbine e.g. via stealth technology to reduce the turbine's RCS.
- Remove the clutter from the radar's vision, e.g. blanking or suppressing of radar cells where turbines are known to be.

The following sections discuss current and future technologies that have been suggested for the US market.

5.2.1. Radar Upgrade

Radar upgrades are pertinent to the US due to the aging nature of the US radar fleet. Ken Kingsmore from the DOD (cited in NWCC 2006) explains that prior to September 11, 2001 the Joint Radar Planning Group in the US, who manage long range radar assets, focused primarily on maintaining border sites such as Hawaii, Alaska and Guam; leaving internal radars to remain untouched. After the September 11 terrorist attacks however, the group became more inwardly focused adding 170 additional sites covering mainland US. Few radars have been updated in the last decade. Kalinowski (cited of www.faa.gov 2010) highlights that, due to their age, many current FAA radars have limited capability to filter out clutter. In addition, making adjustments to older radars, e.g. reducing their sensitivity to eliminate clutter, can cause actual targets to be missed.

Gary Seifert, an expert in radar and wind at the Idaho National Laboratory, advocates modern radars are better equipped to deal with turbine impact issues than older radars (cited in NWCC 2006). Modern radars are typically digital (versus analogue) and have a greater band width, which Webster (2010) argues can improve the radar's resolution and ability to track targets between turbines. New radars also include digital processing capabilities such as multidimensional detection, and pulse shapes which can help differentiate between aircraft and wind farms (Brenner *et al* 2008). Brenner *et al* (2008) point out that computing power has increased 600 fold since the 1990s. The older systems are often hard wired and unable to be changed, limiting their flexibility.

Modern radars that have been shown to improve aircraft detection and/or reduce the visibility of wind farms include the Raytheon ASR-11 (produced in Canada) and the UK equivalent, the Lockhead Martin TPS-77, which enable the UK Ministry of Defence to lift objections to over 3,000 MW of offshore wind projects (Webster 2010). A Wind and Radar Expert interviewed by the author advocated "Lockhead TPS 77 is a fabulous radar that is designed to provide advanced targeting and coverage for the military… Published limits (for the radar) indicate it can provide coverage as close as 500m to the edge of the wind farm." Tom Vinson, an AWEA spokesperson interviewed by the author, said the DOD has replaced an old ASR-8 with an ASR-11 at Travis Air Force Base. Vinson stated in the interview that "The DOD are not comfortable to say they validate these mitigations" however, "they would agree this has improved coverage". Vinson also said in the interview that the DOD had committed to a proposal to field test TPS-77 radar, which has been previously field tested in Europe with positive results.

NOAA's NEXRAD radar is also favourable, with its superior processing capability for weather forecasting (Brenner *et al* 2008). For secondary radar systems, Mode Select (Mode-S) radars have the ability to selectively interrogate aircraft and request specific information; however for Mode-S SSR to be effective, all aircraft should be equipped with Mode-S compliant transponders (Kelly 2011).

Although each of these modern systems has a greater ability to manage the effects of wind turbines, at present no radar is capable of distinguishing a wind turbine echo from a valid aeroplane target echo and therefore no system can consistently provide un-degraded coverage in the area of wind farms (Kelly 2011). This view was supported by the Wind and Radar Expert interviewed by the author who said:

> “You can not completely eliminate clutter. New software allows you to track… right up to the edge of a turbine and then pick it up right after the turbine, therefore reducing the size of areas without coverage… Raytheon’s ASR11 is very effective at reducing zones with poor visibility to one or two (radar) cells either side of a turbine.”

Geoff Blackman, a consultant on wind radar issues for Westslope Consulting, recommends older US ATC radars such as the ASR-8 (38 in US) and ASR 9 (135 in US) radars should be considered for replacement with ASR-11 radars (cited in NWCC 2010, p25) due to their improved ‘clutter’ processing capability. Blackman added that some of the newer radars already installed might cope with wind farm interference through additional software upgrades. Tom Vinson, an AWEA spokesperson interviewed by the author, said
“The only issue (for radar upgrades) is cost. A Lockheed radar is in the vicinity of $15 - $20 million and is not going to be viable everywhere; particularly for single developer projects. Only areas with multiple developer interests will, most likely, be able to afford such a cost.”

5.2.2. Software Upgrades

The following software upgrades can be added to modern radars or digitised older radars to improve their coverage of areas with wind turbines. The following subsections describe each software upgrade.

Concurrent Beam Processing

Concurrent beam processing involves two radar beams, one high and one low, which are obtained and processed simultaneously. This helps identify wind farm clutter from actual aircraft (Webster 2010). Lok and Drake (2009) established that tests in Stockholm in 2005, FAATC in 2007, and Travis Air Force Base in 2008 have shown the advantages of concurrent beam processing over standard switched beam configuration. Tests at Altamont

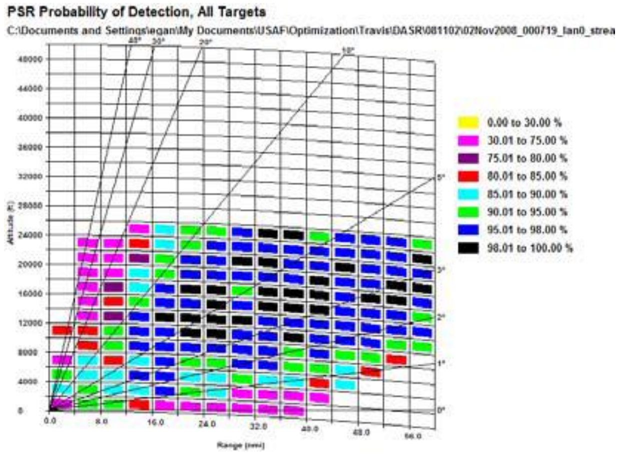
Pass Wind Farm showed ~20% improvement in probability of detection. Geoff Blackman, from Westslope Consulting, recommends this upgrade would be beneficial to Long Range US radars such as FPS-20 series and ARSR 1/2s, and for ATC ASR-11 radars (NWCC 2010, p25) to help them cope with wind turbine interference.

Constant False Alarm Rate (CFAR) Processing

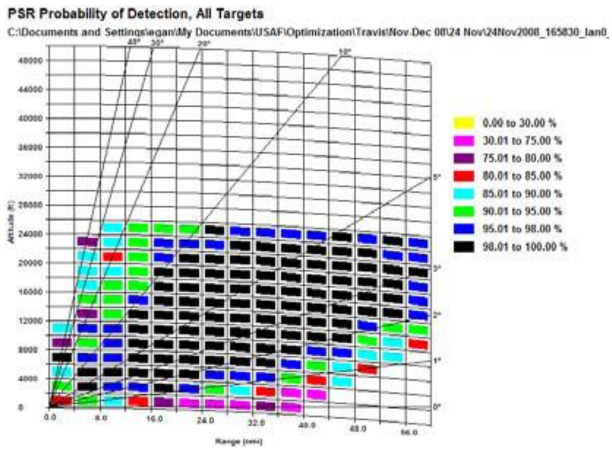
Constant False Alarm Rate (CFAR) processing suppresses data in radar cells that have high level signals from turbines, which contribute to the average background level. Suppressing the high return cells reduces the average background level and detection threshold, which improves the radar's ability to detect aircraft over wind turbines (Webster 2010). CFAR processing can be implemented manually using a map of known turbine positions or automatically using turbine positions from the radar's track extractor. Butler and Johnson (2003) state the manual method is the least demanding as it only affects the radar signal processor. However, CFAR processing would be considered ineffective if the turbines are so dense they raise the background level in all cells.

Enhanced Tracking Techniques

Enhanced tracking techniques are a proposed mitigation, which is in the process of implementation and evaluated on ASR-11 radar systems (Lok and Drake 2009). The enhancements aim to look over (rather than through) the turbines by increasing the antenna tilt and altering the radar's beam transition. The following figure indicates the improvements to probability of detection that can be made with such techniques.



Probability of detection before: 67.53%



Probability of detection after: 92.72%

Figure 16 – Enhanced Tracking Techniques Testing (Lok & Drake 2009)
Source: Lok & Drake 2009

Webster (2010) supports this research arguing increasing the height of radar installation, or using increased antenna elevation angle, has been shown to eliminate a significant portion of performance problems.

High Resolution Clutter Mapping

Clutter maps store information about the average background clutter for successive radar cells. Clutter maps can be incorporated into the MTI/MTD configuration. Decreasing the size of clutter map cells will increase the number of cells between turbines and in turn the probability of detecting aircraft between cells (Butler and Johnson 2003). Implementation of this mitigation requires a wide instantaneous band width transmitter and receiver. In addition, a signal processor and plot and track extractor that can cope with high data rates and volumes (Butler and Johnson 2003). Geoff Blackman from Westslope Consulting, suggests that enhanced clutter map processing is useful on ARSR-4 long range radars to help see through clutter, but notes that it requires a redesign of many of the radars essential components (cited in NWCC 2010).

5.2.3. Gap Filler Radars

Gap filler radars, are secondary radars which are strategically placed to cover an area obscured by a wind farm (Webster 2010). Brenner *et al* (2008) describes how a second view of the obscured area, provided by the gap filler radar, makes it possible to process the effect of wind farms out through data fusion (p 9). Levitan (2010) supports this theory explaining that shortwave radars placed within or adjacent to the wind farm can work in tandem to provide the extra coverage required.

X -band panel and gap filler radars have been identified as possible solutions which have been trialled on NEXRAD weather radars. Studies for application on long range primary radar are also being conducted (Lok and Drake 2009). Raytheon have conducted tests using X-band gap filler and panel radars to cover targets above the wind farm, noting that the narrow pencil beam is able to avoid interference as opposed to the wide beam radars already in place. The following diagrams illustrate how gap filler radars provide an additional view of the same region, can cut through clutter using beam radars, or can look over clutter using elevated views.

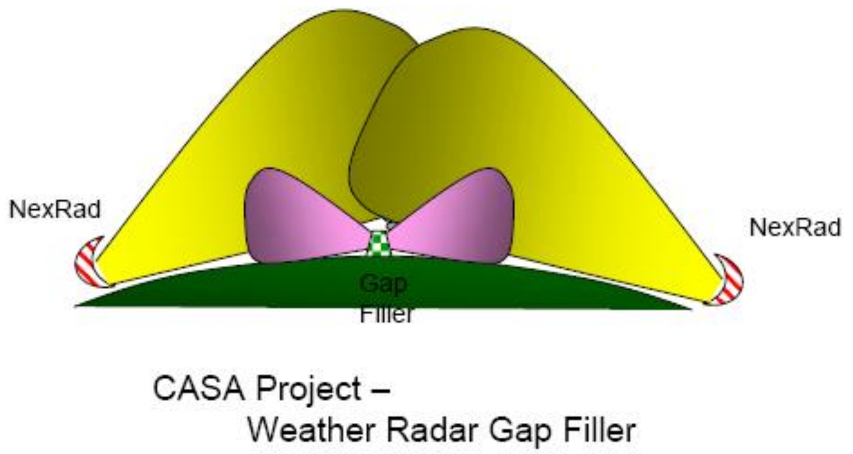


Figure 17 - Gap Filler Radar
Source: Lok and Drake 2009

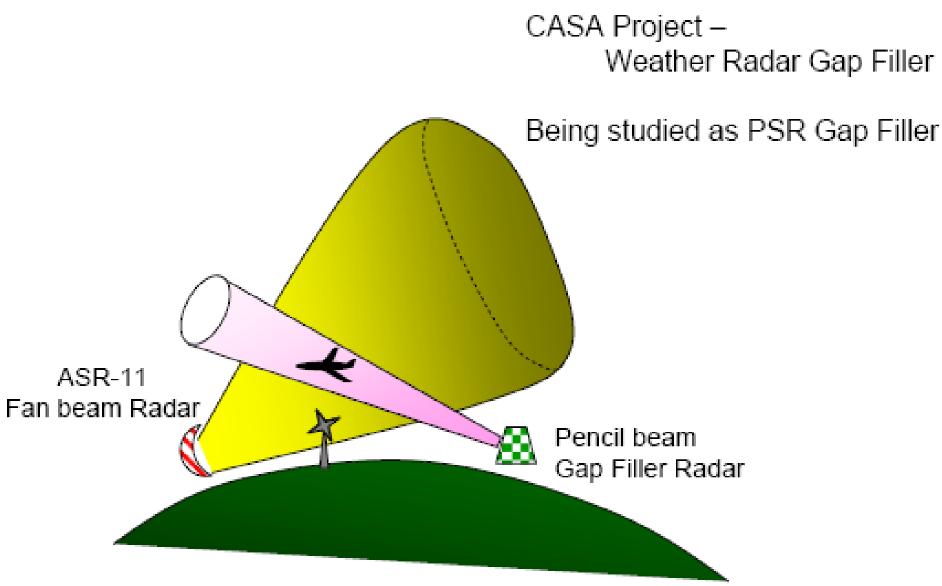


Figure 18 - Pencil Gap Filler Radar
Source: Lok and Drake 2009

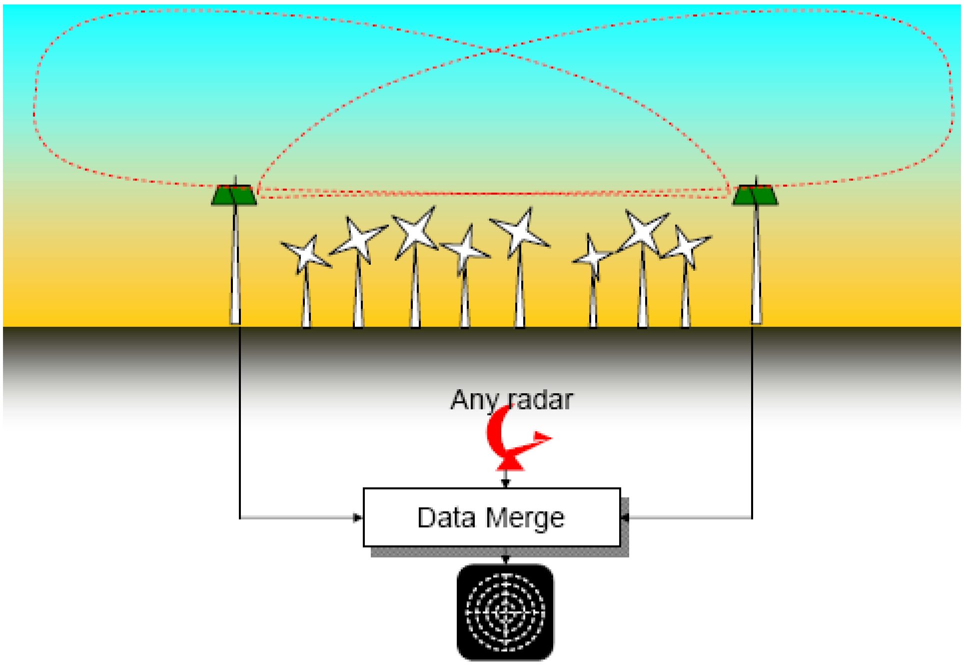


Figure 19 – X Band Panels
Source: Lok and Drake 2009

Lok (2009) identifies this mitigation as suitable for ATC radars, such as ASR–10, ASR-11, and ASR- 23, as well as LRR. Testing of this mitigation has been carried out on an ASR-11 radar at Travis Air Force Base and further testing was scheduled for late 2010 on an ASR-10 radar in the Netherlands (cited in NWCC p, 21). From interviews conducted by the author with a Wind and Radar Expert it was highlighted that, “X band radar is very effective at picking up aeroplanes in between turbines. Data gathered in Oregon showed it could track private aircraft without transponder before, after, and over a wind farm; while long range could only see before and after a wind farm”. Lok (2010) does however note complications with the implementation of x-band panels due to the growing height of turbines and the requirement for panels to be positioned higher than the turbines (cited in NWCC 2010).

Kelly (2011) advocates gap filler radar plays an important role in the UK in enabling ‘blanking’ of main radars. National Air Traffic System En-Route Ltd (NERL) policy requires a minimum of three radars to cover a wind farm area before one can be blanked. Gap fill radars help provide the additional views required. Webster (2010) points out that a gap filling radar by Pager Power, at the low cost of $250,000, allowed the implementation of multiple MW of wind power in Scotland, while not reducing the level of detection in the radar. Brenner *et al*. (2008) recommends developers should have the option to help fund gap-filler radars, or long distance radars. Brenner *et al* (2008) suggests the contribution would equal a few percent of the turbine farm construction costs; estimating the cost of a single radar as between $3-8 million, relatively small when compared to the $2-4 million cost of a single turbine.

5.2.4. Stealth Turbines

Stealth turbines are focused on lowering the RCS of wind turbines by altering the shape of turbine components and using radar absorbing material (RAM) on the turbines (Bryanton *et al* 2007). This can reduce the clutter effects of the wind farm by either altering the Doppler return of the turbines, so it falls outside the detectable range of the radar, or by making the turbine's Doppler return uniquely identifiable and able to be rejected by the radar (Raytheon 2006). RAM can be either active or passive. Passive RAM works by phase cancellation or absorbing and converting electromagnetic energy to heat. Active RAM, also known as phase-switched screens (PSSs), delivers low reflectivity by redistributing the electromagnetic energy incident over a wider bandwidth (Bryanton *et al* 2007). A Wind and Radar Expert interviewed by the author thought positively of stealth turbines, advocating "It can reduce the distance at which turbines interfere with radar by around 30%. Allowing you to site turbines closer to radar without interfering with it."

This mitigation is still in the testing phase with turbine manufacturers such as Vestas and QinetiQ leading research and design. Studies by Bryanton *et al* (2007) identified the main sources of scattering on turbines, and delivered prototype RAM components for the Vestas V82 turbine (p4-5). The study revealed the main areas of mono scattering were caused by the tower (75%) and the turbine blades (20%).

The required RCS reduction for each turbine component was calculated to be: tower 20 dBms, blade 10 dBms, and nacelle 15dBms. RAM design was delivered via a polycarbonate skin with a foam core which was considered low maintenance, light weight and fire retardant (Bryanton *et al* 2007). Results of the study indicated the RCS of the tower and the nacelle can be reduced significantly with shaping alone. RAM components for the turbine blades further reduced the RCS (Bryanton *et al* 2007). QinetiQ has tested its prototypes on shorter-wavelength radars, which they claim also significantly reduce the RCS (Brenner *et al* 2008).

Pinto (2006) outlines key design requirements for stealth turbines as the ability to: reduce turbine RCS, endure UV exposure and a temperature range of -40 to +60, and cost less than 10% of the overall turbine. Brenner *et al* (2008) comments that the impacts of the RAM layer on aerodynamics and turbine longevity is currently unknown. QintetiQ alternatively suggests modifications to the inside of the blade, using layers of circuits and reflectors, which they hope would be effective on L-band radar lengths used by US air-defence.

5.2.5. Non-Technical Solutions

Tom Vinson, an AWEA spokesperson interviewed by the author, indicated the solutions for turbine impacts on testing and training routes "are not as technical" but "more operational", for example "curtailing a wind farm during a military testing period" or "altered training routes". Other non-technical mitigations that have been proposed for radar include:

- Upgrades to navigational aids, published data or Notices to Airmen, and procedural changes where new wind farms have been implemented (Kalinowski 2010, cited on FAA website).
- Policy changes for ATC radars (already adopted in the UK) which dictate that all readings, including false returns from wind farms, must be treated as real aircraft; meaning a minimum lateral separation of 5nmi should be maintained where critical air surveillance operations take place (DOD 2006).
- Additional training of ATC staff to help them discriminate between wind farm clutter and aircraft (Webster 2010). Butcher (2010) however suggests for weather radar that a single turbine can be accommodated by meteorologists, but an entire farm is difficult to mentally account for.
- Mandating that aircraft near and above wind farms have secondary radars in use (Brenner *et al* 2008).

5.3. Evaluation of Proposed Solutions

The solutions to reduce the interference of wind turbines with radar and military sites seem plentiful, although the viability of each can be restricted by cost, development phase and acceptance by the DOD. A Wind and Radar Expert interviewed by the author said, "Integrating infill or gap fill radars will be the most promising mitigation in the short term. That would be followed by improved software mitigation techniques. In the longer term stealth technology, replacing old radars with newer radars, and integrating advanced signal processing algorithms are promising solutions." In broad support of this Tom Vinson, an AWEA spokesperson interviewed by the author, said the wind industry had come up with a "radar by radar mitigation plan". Vinson advocated the best value would be in mitigations that could "clear the most projects". The practicality of such a plan will be dependent on funding and cooperation between government agencies and wind developers.

6. Cooperation, Funding & Research

The Wind and Radar Expert and AWEA representative, interviewed by the author, both listed cooperation between government agencies and wind developers, dedicated funding, and a common research plan as necessities for expanding the range of approved mitigation solutions available to wind/radar concerns. The following section reviews the progress made to date in these areas and highlights areas where future effort is still required.

6.1. Cooperation

Numerous efforts have been made by industry groups and government organisations to bring together the wind energy developers, radar experts, and government defence agencies to help resolve wind/radar concerns. Despite extensive consultation, outlined in the table below, the US progress to resolve wind/radar concerns appears slow.

Year	Key interactions
2005	• Congress mandates DOD study into wind/radar interactions. • The Californian DOD and Wind Industry work to identify areas for potential wind development which are not subject to radar issues.
2006	• DOD delivers *'Effect of Windmills on Military Readiness.'* The report describes the science of possible impacts for select groups of radar and mission types.
2007	• June – FAA/DHS include information on the FAA website which shows most long range radar systems. NEXRAD and DOD flight paths are added over time. • October - Federal agencies and the wind industry meet at Sandia National Laboratory to discuss technical arguments about wind/radar impacts and tools to assess the impacts. • November – Federal agencies and the radar industry meet at Idaho National Laboratory to discuss the impacts and brainstorm research and development topics.

Year	Key interactions
2008	• January - DHS brings government and radar industry experts together to help deliver the JASON report “*Wind Farms and Radar*”. • September - FAA Competition for the Skies Conference which involved side meeting with wind industry, DOD, DHS, NOAA, and FAA and agreement by all parties to develop a joint research and development plan to study and prove mitigation options. • October - San Antonio Surveillance Conference. DOE and AWEA attend DOD/DHS/ NOAA/FAA conference to provide a wind industry perspective on the issue and define what is needed. They recommend the DOE to be the facilitator of joint efforts.
2009	• February – US and British agency and industry counterparts meet to discuss points and merits of British model of collaboration (Aviation Plan and MOU) • October – AWEA, DOD, DHS, FAA, NOAA and DOE discuss progression towards an Memorandum of Understanding, and research and development
Ongoing	• AWEA continues to work with DHS and other federal agencies to develop a plan for radar and wind farm modelling tool • AWEA developing a list of candidate research and development activities as a first step towards a US Aviation/Weather Plan • Individual developers interface with DOD/DHS/FAA/NOAA on specific projects • WINDPOWER 06 (PA), 07 (CA), 08 (TX), 09 (IL): Listening sessions for the government where it is agreed that all stakeholders need to improve their efforts. Sessions have delivered progress in identifying stakeholders, understanding the nature of impacts, and agreeing on collaborative work.

Table 2 - History of US Cooperation
Source: Webster 2010

Tom Vinson, an AWEA spokesperson interviewed by the author, shared the following view on collaboration to date, “I would say there is agreement that there are challenges and alignment as to what those challenges are. There is also broad agreement there are technological solutions that are available, or could be available."

One major proposal that has failed to gain traction to date is to follow the UK model for resolution. Tom Vinson (2010) from AWEA advocated the British wind energy association – UK Renewables – was able to negotiate with the Ministry of Defence and Civil Aviation Authority to bring about early agency engagement, clear timeframes for resolving conflict, and provide a research and development agenda (cited in Magnuson). Warwick (2010) highlights UK Renewables and the UK government formed a consortium to fund mitigation research that allocates funding on the likelihood of success and wind capacity at stake. The UK aviation plan recognises "There is no universal solution to mitigate the effects of wind turbines on radar" hence making their mission to "develop a suite of mitigation solutions endorsed by aviation stakeholders" that facilitates "constructive dialogue" between wind developers and aviation stakeholders (Blackman 2009). In 2008 the UK plan was focused on gap filler radars, mandatory transponder zones, studies into SPE-3000, Raytheon radars, stealth technology, and web based screening tools (Blackman 2009).

6.2. Research & Funding

6.2.1. Research

Seifert (2006) highlights that only experts from the DOD, FAA and DHS can determine whether a mitigation is acceptable. Therefore further research from these bodies is required to expand the range of viable mitigations. Tom Vinson, an AWEA spokesperson interviewed by the author, said the DOD is working on collaborative research with the DOE, DHS and MIT Lincoln Laboratory, which involves "field testing the Lockhead TPS 77" and "looking at testing 'off the shelf' infill and gap fill radars that have had limited field trials". A Wind and Radar Expert interviewed by the author added, "I believe they're looking at what changes can be made to the dynamic mapping e.g. RAG mapping and clutter mapping.
They're also using clutter mapping and combining that with new post processing systems and improved filtering mechanisms." From the author's interview with Vinson, it was identified the timeframe for this testing is the "next 2-3 years". Vinson however, questioned whether these research areas were at the "top of the list" in terms of "what would clear the most projects".

6.2.2. Funding

Brenner *et al* (2008) argues there is significant potential for mitigations however there is currently no source of funding to test proposed mitigations in the practical environment. NOAA has a well established research plan but no source of sufficient funding to execute it. At present neither wind farm manufacturers nor the government support significant research activities (Brenner *et al* 2008). A recommendation of the *JASON* report was that parties on both sides should provide funding towards this testing (Brenner *et al* 2008.). Dougherty (2008) proposes $30 million in congressional appropriations for a 5 year effort with a split of the costs:

- $10 million to federal agencies to develop wind-radar impacts projects.
- $10 million to a public-private partnership to test existing and emerging technology fixes.
- $5 million to develop and maintain a 'wind-radar impacts toolkit' focused on pre-screening capabilities and viable mitigation options.
- $5 million to an overseeing organisation to manage projects.

6.3. Issue Next Steps

So what are the favoured next steps to help progress these issues? Tom Vinson, an AWEA representative interviewed by the author, suggests 'early engagement' needs to be defined for the FAA impact assessment process. Vinson said if agencies want developers to engage 12-18 months prior to construction, "There needs to be agreement about what can be discussed at that stage and what information developers need to have. Micro-siting of the turbines for example doesn't happen until fairly late." When interviewed by the author, Vinson also said an agreed research, development and validation plan is important. Vinson said "Now the debate is around how we validate solutions, which ones do we validate, and who is going to pay for that. Once a solution has been validated there will also be debate around who pays for its deployment."

A Wind and Radar Expert, interviewed by the author supported the need for a research agenda, "The most important thing to do now is push the research agenda, the military will like options such as TPS 77, but these incur a significant investment." The Wind and Radar

Expert suggested instead that research into synchronising "multiple radars looking at the same area" while avoiding "issues with accuracy" would be beneficial to gap filler solutions.

The Wind and Radar Expert also suggested that improvements to the current technology validation process are required, "Radars are much more capable than you'd expect, it's the processes that we approve them under that is concerning. Certification can take 2-3 years… The time it takes to certify and accept new technologies is a major issue."

7. Evaluation of Pilot Study Results

This pilot study has broadly fulfilled the requirements set out in the objectives; information gathered has allowed the issue to be defined, impact of concerns to be identified, and possible solutions to be highlighted; therefore providing a platform for further research into more detailed aspects of the issue covered.

A limitation of this pilot study is the small number of participants interviewed. Only eight participants were invited to interview due the amount of time required to obtain ethical approval for the research. Of these eight, only three were able to participate. For more robust results, the findings could be tested against a wider populace. In addition, as the topic broadly covered a selection of key radar types and military site issues, only a selection of solutions could be included. More detailed analysis of solutions for particular radar or military site issues could be covered in further research.

8. Conclusion and Recommendations

Genuine concerns have been raised in the US around the impact of wind turbines on radar and military sites. The concerns are varied; however this pilot study shows that each concern is theoretically plausible. Additional clutter, shadow, seismic noise and flight obstruction are the main concerns the DOD has raised for proposed wind projects. A particular concern for the DOD appears to be the use of radar clutter and shadow zones by unfriendly aircraft to move below the radar; enabling them to potentially conduct missions undetected.

These DOD concerns, raised through the FAA turbine impact assessment process, have had an extensive impact on the rapid development of the US wind industry. They have contributed to the delay of US installed wind capacity, which is currently falling short of ‘20/30’ installation targets. From analysis results it appears feasible this could prevent the US from reaching its target of 20% of energy from wind energy by 2030. A key challenge for the FAA impact assessment process is to provide an objective outcome that is respected by Congress and is not overturned by alternative political agendas.

The proposed solutions available to help resolve wind turbine interference with radar and military sites are vast; with gap fill radar, software upgrades, radar upgrades, and stealth technology as favoured solutions. Issue experts concur that an agreed research, development, and validation process is important to expand the range of mitigating technologies available. Pivotal to this agreement is the funding source for such activities.

On the basis of this pilot study, recommended areas for further research include:

1. Detailed analysis of solutions for a specific radar type or military site concern.
2. Technical research into enabling technologies (for example synchronisation of multiple radar views).
3. Detailed analysis of proposed policy solutions that could provide incentives for cooperation and change.

9. Glossary

Term	Definition
20/30	DOE assessment that 20% of US energy could come from wind energy by 2030
ARRA	American Recovery and Reinvestment Act
ARSR-1 /ARSR-2 /FPS-20	1950's model, 2D, L-band frequency long range radars with a maximum range of 200 miles. Radar model is being replaced with ARSR – 4 (Radomes 2011).
ARSR 3	3D long range radar providing coverage up to 240 miles (Radomes 2011).
ARSR-4	The most modern 3D long range surveillance radar. Radar provides improved reliability, improved ability to track small object (via minimised clutter), and coverage up to 250 nautical miles (Aftergood 2000).
ASR-8	Analogue Air Surveillance Radar with limited processing capability when compared to modern radar types. Radar type is being replaced with modern ASR-11 radar (Wolff 2011).
ASR-10	Flexible, modern radar that meets the requirements of the US FAA / DOD ASR-11 next generation radar (Raytheon 2011).
ASR-11	Digital Air Surveillance Radar providing PSR coverage of 60 miles and SSR coverage of 120 miles (Raytheon 2011). Radar provides digital processing, improved reliability, and improved performance not available in earlier models e.g. ASR-8 radar (Wolff 2011).
ATC	Air Traffic Control
AWEA	American Wind Energy Association
CFAR	Constant False Alarm Rate
Clutter	Electromagnetic energy echoes of unwanted targets
CTBT	Comprehensive Test Ban Treaty
dDms	Decibels Per Metre Squared
DHS	Department of Homeland Security
DOD	US Department of Defence
DOE	US Department of Energy

Term	Definition
Doppler	Apparent change in frequency or pitch when a moving object moves towards or away from a radar. Doppler monitoring indicates whether an object is moving towards or away from a radar and can be used to calculate the speed of movement (Wolff 2011).
EWR	Missile Early Warning Radar
FAA	Federal Aviation Administration
FAATC	Federal Aviation Administration Technical Centre
ft	Feet (3.28 ft equal 1 meter)
Km	Kilometres
LRR	Long Range Radar
Mode-S	Mode Select
MTD	Moving Target Detection
MTI	Moving Target Indication
MW	Megawatts
NERL	(National Air Traffic System) En-Route Ltd
NEXRAD	Next Generation Weather Radars
Nmi	Nautical Miles
NOAA	National Oceanic Atmospheric Administration
PSR	Primary Surveillance Radar
Radar	Radio Detection And Ranging
Radar Cell	A radars view is split into a grid pattern. Each grid square is a radar 'cell' which shows information for that specific area. Cells are used to compare and contrast returns with other cells in the grid (DOD 2006).
RCS	Radar Cross Section – scale of electromagnetic energy reflectivity of an object
SSR	Secondary Surveillance Radar
Targets	Object of interest in the line of sight of a radar
TARS	Tethered Aerostat Radar System. Balloon-bourne radar system used by government agencies to counter illegal drug trafficking (Aftergood 2000).
UK	United Kingdom
US	United States of America

Term	Definition
WSR-88D	Next Generation weather radar that use Doppler maps to illustrate rain, hail, and snowfall patterns (DOD 2006)

10. References

Aftergood, Stephen. 2000. *Strategic Air Defence Systems.* http://www.fas.org/nuke/guide/usa/airdef/index.html (Accessed Jan 20, 2011).

Auld, A. 2006. *Options for Mitigating the Impact of Wind Turbines on NERL's primary radar infrastructure. http://webarchive.nationalarchives.gov.uk/+/http://www.berr.gov.uk/files/file37011.pdf* (Accessed Dec 10, 2010).

AWEA. 2011. *AWEA US Wind Industry First Quarter 2011 Market Report*. http://www.awea.org/learnabout/publications/reports/AWEA-US-Wind-Industry-Market-Reports.cfm (Accessed Jun 22, 2011).

AWEA. 2011. *AWEA US Wind Industry Year-End 2010 Market Report*. http://www.awea.org/learnabout/publications/reports/AWEA-US-Wind-Industry-Market-Reports.cfm (Accessed Feb 26, 2011).

AWEA. 2010. AWEA *US Wind Industry Annual Market Report Year Ending 2009*. http://www.awea.org/learnabout/publications/reports/AWEA-US-Wind-Industry-Market-Reports.cfm (Accessed Oct 1, 2010).

AWEA. 2009. *American Wind Energy Association Annual Wind Industry Report Year Ending 2008*. http://www.awea.org/learnabout/publications/reports/AWEA-US-Wind-Industry-Market-Reports.cfm (Accessed Oct 1, 2010).

BP. 2010. *BP Statistical Review of World Energy*. http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2010_downloads/statistical_review_of_world_energy_full_report_2010.pdf (Accessed Sept 20, 2010)

Brenner, Michael. *et al*. 2008. *JASON Report: Wind Farms and Radar*. Virginia, USA: The Mitre Corporation.

Bryanton *et al*. 2008.*BERR Stealth Technology for Wind Turbines: Final Report, December 2007.*http://www.bwea.com/pdf/AWG_Reference/0805%20BERR%20Stealth%20Technology%20for%20Wind%20Turbines.pdf (Accessed Mar 21, 2011).

Butcher, Brandon. 2010. "UMASS Lab Works to Solve Doppler Radar Problems that could Aid Wind Energy Industry". *CBS3 Springfield, November 22*. http://www.cbs3springfield.com/news/local/UMASS-Lab-Works-to-Solve-Doppler-Radar-Problems-that-Could-Aid-Wind-Energy-Industry-109890064.html (Accessed Jan 21, 2011).

Butler, M.M. and Johnson, D.A. 2003. *Feasibility of Mitigating the Effects of Wind Farms on Primary Radar.* http://www.bwea.com/pdf/AWG_Reference/0306%20BERR%20Feasibility%20of%20mitigating%20the%20effects%20of%20wind%20farms%20on%20primary%20radar.pdf (Accessed Mar 21, 2011).

Coal Geology. 2010. "Caithness Shepherds Flat wind project will avoid 1,215,991 tons of carbon dioxide per year". *Coal Energy, October 8*. http://coalgeology.com/caithness-shepherds-flat-wind-project-will-avoid-1215991-tons-of-carbon-dioxide-per-year/7164/ (Accessed Jun 2, 2011).

DOD. 2006, 2010, 2011. *See United States Department of Defense.*

DOE. 2008. *See United States Department of Energy.*

Dougherty, P.J. 2008. “Mitigating Wind Energy Impacts on Federal Radar Systems and Agency Operations” Presentations presented at the *Federal Aviation Administration (FAA) Competition for the Sky Conference. Las Vegas, NV, September 28 – October 2 2008* http://vwec.cisat.jmu.edu/workshop/Presentations/radar%20CSKY%20Presentation%20-%20PJ%20Dougherty.pdf (Accessed Jan 11, 2011).

Eilperin, Juliet. 2010. “Pentagon Objections Hold Up Oregon Wind Farm” *Washington Post,* April 15. http://www.washingtonpost.com/wp-dyn/content/article/2010/04/15/AR2010041503120.html (Accessed Jun 15, 2011).

EUMETNET. 2005. *Impact of Wind Turbines on Weather Radar*. http://www.wmo.int/pages/prog/www/TEM/SG-RFC06/Wind%20turbine%20vs%20weather%20radars.doc (Accessed Aug 4, 2011).

Federal Aviation Administration (FAA). 2010. *Testimony - Statement of Nancy Kalinownski*. http://www.faa.gov/news/testimony/news_story.cfm?newsId=11599 June 29 (Accessed Dec 10, 2010).

Federal Aviation Administration (FAA). 2000. *Advisory Circular AC 70/7460-2K: Proposed Construction or Alteration of Objects that May Affect the Navigable Airspace*. http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/22990146db0931f186256c2a00721867/$FILE/ac70-7460-2K.pdf (Accessed Mar 1, 2011).

Freshfields Bruckhaus Deringer US LLP. 2009. *Briefing: Expansion of Clean Energy in US (tax incentives and cash grants).* www.freshfields.com/publications/pdfs/2009/jul09/26336.pdf (Accessed Sept 20, 2010).

Fort Worth Star. 2010. “Wind Farms May be Causing Radar Problems.” *Fort Worth Star-Telegram,* April 28. http://www.military.com/news/article/wind-farms-may-be-causing-radar-problems.html (Accessed Jan 10, 2011).

Kelly, Brendan. 2011. *NATS En Route plc (NERL) ATM Policy Statement 3.1: Mitigating the effects of wind turbines of NATS En Route Ltd (NERL) operations.* http://www.nats.co.uk/wp-content/uploads/2011/01/Mitigating-the-effects-of-wind-turbinesV3.1.pdf (Accessed Feb 14, 2011).

Learn, Scott. 2010. “Air Force Concerns About Radar Interference Stall Huge Oregon Wind Farm”. *The Oregonian*, April 14. http://www.oregonlive.com/environment/index.ssf/2010/04/air_force_concerns_about_radar.html (Accessed November 21, 2010).

Lemmon, John, J., Carroll, John, E., Sanders, Frank, H., and Turner, Doris. 2008. *NTIA Technical Report TR-08-454: Effects of Wind Turbines on Air Traffic Control Radars*. http://www.bwea.com/pdf/AWG_Reference/0807%20Assessment%20of%20Effects%20of%20Wind%20Turbines%20on%20ATC%20radars.pdf (Accessed May 22, 2011).

Levitan, Dave. 2010. “Fears of Radar Interference Threaten Oregon Wind Farm But Solution Exists: Software and Hardware Upgrades Can Eliminate the Problem.*” Solve Climate News,* April 19. http://solveclimatenews.com/news/20100419/fears-radar-interference-threaten-oregon-wind-farm-solutions-exist (Accessed Jan 10, 2011).

Lok, Y, Francis., and Drake, Peter, R. 2009. “Raytheon Wind Farm Mitigation Update”. Presentation presented at the *National Wind Coordination Collaborative: State of the Art in Wind Sitin Seminar,Washington, DC, October 20-21, 2009.* http://www.nationalwind.org/assets/blog/Lok.pdf (Accessed Mar 10, 2011).

Magnuson, Stew. 2010. *British Model May Hold Key to Solving Wind Energy, Radar Clutter Problem.* NDIA Business and Technology Magazine. October. http://www.nationaldefensemagazine.org/archive/2010/October/Pages/BritishModelMayHoldKeytoSolvingWindEnergy,RadarClutterProblem.aspx (Accessed Jan 10, 2011).

Merkley, J. 2010. Press Release “Shepherds Flat Wind Farm Will Move Forward”. *Jeff Merkley*, April 30. http://merkley.senate.gov/newsroom/press/release/?id=D02CE5E6-0C40-43D8-A1BC-9CE9804DEB38 (Accessed Apr 9, 2011).

NWCC. 2010. *Meeting Proceedings of the National Wind Coordination Collaborative: State of the Art in Wind Siting: A Seminar, October 20-21, 2009.* Washington DC: NWCC. http://www.nationalwind.org/assets/publications/State_of_the_Art_in_Wind_Siting_Proceedings_PrePublication_Copy.pdf (Accessed Feb 14, 2011).

Radomes. 2011. *ARSR 1,2,3,4*. http://www.radomes.org/museum/equip/arsr-1234.html (Accessed Aug 4, 2011).

Raytheon. 2011. *Radar Capabilities - Land*. http://www.raytheon.com/capabilities/radar/land/index.html/ (Accessed Mar 11, 2011).

Reuters. 2010. “‘Stealth' Wind Turbine Blade May End Radar Problem’. *Reuters, Jan 27th*. http://news.cnet.com/8301-11128_3-10442876-54.html (Accessed Jan 11, 2011).

Schleck Associates PA. 2010. *Radar Issues with Wind Turbines*. http://schleckpa.com/legal-topics/environmental-law/articles/radar-issues-with-wind-turbines (Accessed Jan 24, 2011).

Science Daily. 2011. “Wind Turbines: In the Wake of the Wind”. Science Daily, April 27. http://www.sciencedaily.com/releases/2011/04/110426151040.htm (Accessed Jun 12, 2011).

Seifert, Gary. 2009. *Wind Radar Issues*. http://www.regionalwind.org/images/Wind_Radar_siting_webinar_09.pdf (Accessed Jan 21, 2011).

Seifert, Gary. 2006. *Wind Radar Interference.* http://www.windpoweringamerica.gov/pdfs/workshops/2006_summit/seifert.pdf (Accessed Nov 22, 2011).

Styles, Peter *et al*. 2005. *Microseismic and Infrasound Monitoring of Low Frequency Noise and Vibrations from Wind Farms*. http://geophysics.esci.keele.ac.uk/resources/docs/Final_Report.pdf (Accessed Aug 3, 2011).

The Associated Press. 2010. “AF: Ore. Wind Farm Would Cause Radar Clutter”. *The Associated Press, April 15.* http://www.airforcetimes.com/news/2010/04/ap_airforce_oregon_wind_turbines_041510/ (Accessed Oct 23, 2010).

United Kingdom Royal Air Force. 2005. *The Effects of Wind Turbines on ATC Radar*. http://www.bwea.com/pdf/AWG_Reference/050510%20RAF%20Report%20on%20Wind%20Farm%20effects%20on%20ATC%20radar.pdf (Accessed Nov 22, 2010).

United States. Department of Defence (DOD). 2011. News Release: “DOD Releases 2012 Fiscal Budget Proposal”. *DOD*, February 14. http://www.defense.gov/releases/release.aspx?releaseid=14263 (Accessed June 12, 2011).

United States, Department of Defence (DOD). 2010. *About the Department of Defence (DOD)*. http://www.defense.gov/about/#mission (Accessed Jun 2, 2011).

United States. Department of Defence (DOD). 2006. *Report on Congressional Defence Committee: Effect of Windmill Farms on Military Readiness*. www.defence.gov/pubs/pdfs/windfarmreport.pdf (Accessed September 17, 2010).

United States. Department OF Energy (DOE). 2008. *20% Wind Energy by 2030: Increasing Wind Energy’s Contribution to US Electricity Supply.* http://www1.eere.energy.gov/windandhydro/pdfs/41869.pdf (Accessed Sept 1, 2011).

United States. Department of Energy (DOE). 2008. *Federal Wind Siting Information Centre.* http://www1.eere.energy.gov/windandhydro/federalwindsiting/ (Accessed Jan, 21 2011).

United States Government. 2010. *National Security Strategy 2010*. www.whitehouse.gov (Accessed September 18, 2010).

Warwick, Graham. 2010. "Radar Upgrades Cut Wind Farm Interference*". Aviation Week, Sept 28.* http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=awst&id=news/awst/2010/09/20/AW_09_20_2010_p68-254521.xml (Accessed Jan, 24 2011).

Washington Post. 2010. "Pentagon Objections Hold Up Oregon Wind Farm" *Washington Post,* April 15. http://www.washingtonpost.com/wp-dyn/content/article/2010/04/15/AR2010041503120.html (Accessed Jun 15, 2011).

Webster, Stu, S. 2010. *Testimony of Stu S. Webster, Director of Wind Permitting and Environment, Iberndrola Renewables On Behalf of the American Wind Energy Asssociation Before the Readiness Subcommittee of the House of Armed Services Committee, June 29 2010.* http://democrats.armedservices.house.gov/index.cfm/files/serve?File_id=b0ce6cd5-8590-4b4e-9a64-0b72506fc133 (Accessed November 20, 2010).

Wolff, Chris. 2011.*Radar Tutorial*. http://www.radartutorial.eu/19.kartei/ka03.de.html (Accessed Aug 3, 2011).

Appendix 1: Addendum

Introduction

During the pilot study's research period, an interview with a DOD representative was sort to provide a key stakeholder perspective on US wind/radar issues. While this interview was unable to take place during the research period; post the conclusion of this pilot study David Belote (Director of the US DOD Energy Siting Clearing House) kindly made his time available to the author.

The following addendum shares the outcomes of the author's interview with David Belote and summarises the significance of the interview results to the findings of this pilot study. The interview was conducted over the phone and under the guidance of a DOD media advisor. A recording of the interview was made by the DOD.

Interview Results

Effect of Wind Turbines on Radar (3.2)

David Belote identified "...not being able to track small civilian aircraft" as one of the biggest concerns the DOD have related to wind farms. This interview response supports the pilot study findings that wind turbine shadow and clutter zones can hinder a radar's ability to track aircraft.

Effect of Wind Turbines on Military Sites (3.3)

Commenting on the split between the number of DOD concerns related to radar versus military sites, David Belote explained that some military testing facilities require "an electromagnetic pristine environment" for testing technologies such as stealth and radar. Belote added that the nature of testing is, "…sensitive as we can't talk about the frequency bands we use or what we are testing". Adding, "The Bin Laden raids are a good example of the type of technology we might need to test". In this comment Belote was referring to stealth-modified helicopter technology that is thought to have allowed US Navy Seals to evade the Pakistani radar network (Ross 2011).

Belote indicated the DOD hope to get support for no wind turbine zones around required "pristine" testing sites. These interview outcomes confirm that electromagnetic interference caused by wind turbines is another central concern from the DOD.

DOD Energy Siting Clearing House (4.2.2)

When asked about the impact that the establishment of the DOD Energy Siting Clearing House (Clearing House) has had on improving DOD and wind developer engagement, David Belote reinforced pilot study findings that the Clearing House has already started to deliver positive results, "In the first round we looked at every project held up by the Department of Defense… that was 249 projects covering 6300 turbines… We cleared 229 of them which represent 10GW of renewable energy capacity". Belote commented that the Clearing House "look at the projects from a long range radar angle, a military training angle, and from a military testing perspective." This suggests the Clearing House also provides greater process efficiency than pilot study results indicate existed in the past.

When asked about tools or processes that the Clearing House has put in place to make the assessment of an 'acceptable level' of wind turbine interference more objective, Belote indicated the Clearing House currently uses Graphic Information System visualisation tools and military judgement to conduct an initial assessment. These findings are then backed up by a detailed analysis from the affected department (including some turbine by turbine impact assessment from the 84th Radar Evaluation Squadron). Belote said a desktop modelling tool based on turbine by turbine assessment "is around 18 months away".

Evaluation of Proposed Solutions (5.3)

Commenting on the split between the number of DOD concerns related to radar versus military sites, David Belote said he believed, "Most of the pure radar concerns could go away in the next 3-5 years. Scientists understand it, industry wants to solve it, and government wants to solve it. People will develop techniques to overcome the clutter rejection issues we see."

When asked which proposed technologies are most viable in delivering a wind/radar solution, Belote described the DOD as "technology agnostic" suggesting "there is not enough data to say one technology is better than another." Belote added the DOD is currently testing a number of technology solutions. Stealth turbines however, will not be in the testing mix, "From my experience I know it's difficult to keep stealth stealthy. Stealth works in a given frequency band…its expensive… we aim to deliver solutions to the problem more cheaply and quickly" Belote said. These interview outcomes reduce the pilot study results that stealth turbines could be endorsed by the DOD as a viable technology solution.

Research (6.2.1)

In reference to research being conducted to expand available solutions, David Belote said the DOD have paired up with the DOE and MIT Lincoln Laboratory to conduct "Interagency Field Test and Evaluation". A process designed to compare available solutions. Belote said "They're taking a look at adaptive clutter mapping, in-fill radar, gap fill radar (to see behind turbines), Raytheon concurrent beam process (to track objects over and behind turbines), and Lockheed Martin pencil beam radar." These interview outcomes also show that the DOD has invested over $3 million USD so far to develop a menu of DOD endorsed solutions.

Funding (6.2.2)

When asked about previous and future cost allocation for wind/radar mitigations, David Belote explained that historically "There's really only one example and that's at Travis Air Force Base. Thus far developers have borne the entire cost of optimisation and changes to display." Looking forward Belote advocates that the DOD would be interested in promoting solutions that suit developer finances, "Speaking to industry, 1% of the cost of project seems to be a magic number. If the industry can create solutions such as in fill and gap fill at 1% cost then I think we'll have solutions developers are interested in". These interview results expand the funding perspective provided in the pilot study results.

Issue Next Steps (6.3)

In line with pilot study results, David Belote focused on collaboration when asked about the next steps required to help resolve wind/radar concerns, "…we need to sit down with major developers and those affected, as there needs to be a cost sharing, and negotiate a public private partnership… It won't be easy but it has to be a team effort." Belote Said.

Reference

Ross, Brian. 2011. "Top Secret Stealth Helicopter Program Revealed in Osama Bin Laden Raid" *abc news*. http://abcnews.go.com/Blotter/top-secret-stealth-helicopter-program-revealed-osama-bin/story?id=13530693 (Access Nov 7 2011).